THE ARMIES OF INDUSTRY

I.

OUR NATION'S MANUFACTURE OF MUNITIONS FOR A WORLD IN ARMS 1917-1918

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ILLUSTRATED WITH PHOTOGRAPHS FROM THE COLLECTIONS OF THE WAR AND NAVY DEPARTMENTS

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INTRODUCTION

AS we look back at it now, our war against Germany is beginning to draw into focus as it recedes down the corridor of time. That which only a brief space ago seemed to the world an interminable agony, running without hope of end, now is seen to have been not an indefinite thing after all. It had boundaries, limits, a beginning and an end; and for us the beginning and the end were the 6th of April, 1917, and the 11th of November, 1918.

Here, then, was our war, the greatest in which we ever engaged—a few days more than nineteen months of it. For that struggle we marshaled our resources as they had never been mobilized before. What showing did our resources make, our magnificent industrial resources, in that war, in those nineteen months and five days? What weight of American artillery did they put on the front? How many airplanes and machine guns and high-explosive shell did they materialize, in that war of the definite beginning and the definite ending that now seems almost to have been predestined, if it were not actually foretellable by human judgment?

The answers to some of these questions are disappointing; and the critic who adopts the censorious point of view can make an impressive argument. But that is neither the fair nor the intelligent way of looking at the results of our munitions production in the World War. To gain a correct judgment of the industrial effort one must relive in imagination those months of suspense during most of which there was not the faintest paling of the darkness to foretoken the dawn of peace and victory. Then one can understand why America in her war industry strained every energy toward an ambition that was little concerned with the year 1918; toward an indomitable purpose which admittedly did not bring the full weight of American *matériel* into the struggle even in 1919; which

rather left it for 1920, if the enemy should not yet have succumbed to the crushing American power, to witness the maximum strength in the field of which the United States was capable.

Therefore we find the actual period of hostilities—the period between April 6, 1917, and November 11, 1918—devoted to building the foundations of a munitions industry that should be big enough to accomplish this overwhelming result. We might have made a better showing with our finished war materials, we might have aimed at a quick victory—and we might have failed. We did not take this course. America demanded the insurance that existed in the complete utilization of all her resources; and in the progress of welding those resources into a single vast war machine, such munitions of the more difficult sort as were actually produced may almost be regarded as casual to the main enterprise—mere harbingers of the quantities to come.

The decision to prepare heavily for 1919 and 1920 and thus sacrifice in 1917 and 1918 the munitions which could have been produced at the cost of a less adequate fundamental preparation, was based on sound strategical reasoning on the part of the Allies and ourselves. Looking back at the past, we find that on April 6, 1917, the United States scarcely realized the gravity of what she was undertaking to do. There was a general impression, reaching even into Government, that the Allies alone were competent to defeat the Central Powers in time, and that America's part would be largely one of moral support, with expanding preparation in the background as insurance against any unforeseen disasters. In conformity with this attitude we sent the first division of American troops to France, in the spring of 1917, to be our earnest to the governments and peoples of the Allies that we were with them in the great struggle. Not until after the departure of the various foreign missions which came to this country during that spring did America fully awake to the seriousness of the situation.

All through the summer of 1917 the emphasis upon American man power in France gradually grew; but no definite

schedule upon which the United States could work was reached until autumn or early winter, when the mission headed by Colonel Edward M. House visited Europe to give America place on the Supreme War Council and in the Interallied Conference. The purpose of the House mission was to assure the Allies that America was in the war for all she was worth and to determine the most effective method in which she could coöperate.

In the conferences in London and Paris the American representatives looked into the minds of the Allied leaders and saw the situation as it was. Two dramatic factors colored all the discussions—the growing need for men and the gravity of the shipping situation. The German submarines were operating so effectively as to turn exceedingly dark the outlook for the transport on a sufficient scale of either American troops or American munitions.

As to man power, the Supreme War Council gave it as the judgment of the military leaders of the Allies that, if the day were to be saved, America must send 1,000,000 troops by the following July. There were in France then (on December 1, 1917) parts of four divisions of American soldiers—129,000 men in all.

The program of American coöperation, as it crystallized in these conferences, may be summarized as follows:

1. To keep the Allies from starvation by shipping food.
2. To assist the Allied armies by keeping up the flow of *matériel* already in production for them in the United States.
3. To send as many men as could be transported with the shipping facilities then at America's command.
4. To bend energies toward a big American Army in 1919, equipped with American supplies.

This general agreement or program was a most practical proposition, based on things as they were and not as they might have been. The negotiators looked at the situation with their eyes wide open. At an earlier point in this record* we have maintained the thesis that, due to the failure of those

* See Authors' Foreword, *The Giant Hand.*

in authority to provide an effective form of organization for the War Department, the first six months of the manufacturing program were largely futile, wasted, and abortive, and that in consequence the general munitions-production curve was always at least half a year below what it should have been. Had the industrial situation been different in the fall of 1917, if the war industry had then been reaching the production stage in the more difficult and important branches of supply, instead of being, as it was, still in the planning, development, and preparatory stage, no doubt the Allies would have asked America to play a part even more significant than the one as outlined above. The hope of victory might not have been so long deferred.

In the conferences which laid down the first concerted program of American coöperation sat the chief military and political figures of the principal European powers at war with Germany. In the Supreme War Council were such strategists as General Foch for the French and General Robertson for the British, General Bliss representing the United States. The president of the Interallied Conference was M. Clemenceau, the French prime minister. Mr. Winston Churchill, the minister of munitions, represented Great Britain. Mr. Lloyd-George, the Prime Minister of England, also participated to some extent in the conferences.

Out of such men and such minds came the Interallied Ordnance Agreement. It will be evident to the reader that this agreement must have represented the best opinion of the leaders of the principal Allies. It was developed out of their intimate knowledge of the needs of the situation and concurred in by the representatives of the United States. The substance of this agreement was outlined for Washington in a cabled message signed by General Bliss, of which the more important passages are set down at this point:

The representatives of Great Britain and France state that their production of artillery (field, medium, and heavy) is now established on so large a scale that they are able to equip completely all American

divisions as they arrive in France during the year 1918 with the best make of British and French guns and howitzers.

The British and French ammunition supply and reserves are sufficient to provide the requirements of the American Army thus equipped at least up to June, 1918, provided that the existing 6-inch shell plants in the United States and Dominion of Canada are maintained in full activity, and provided that the manufacture of 6-inch howitzer carriages in the United States is to some extent sufficiently developed.

On the other hand, the French, and to a lesser extent the British, require as soon as possible large supplies of propellants and high explosives: and the British require the largest possible production of 6-inch howitzers from now onward and of 8-inch and 9.2-inch shell from June onward.

In both of these matters they ask the assistance of the Americans.

With a view, therefore, first to expedite and facilitate the equipment of the American armies in France, and, second, to secure the maximum ultimate development of the ammunition supply with the minimum strain upon available tonnage, the representatives of Great Britain and France propose that the American field, medium, and heavy artillery be supplied during 1918, and as long after as may be found convenient, from British and French gun factories; and they ask: (a) That the American efforts shall be immediately directed to the production of propellants and high explosives on the largest possible scale; and (b) Great Britain also asks that the 6-inch, 8-inch, and 9.2-inch shell plants already created for the British service in the United States shall be maintained in the highest activity, and that large additional plants for the manufacture of these shell shall at once be laid down.

In this way alone can the tonnage difficulty be minimized and potential artillery development, both in guns and shell, of the combined French, British, and American armies be maintained in 1918 and still more in 1919.

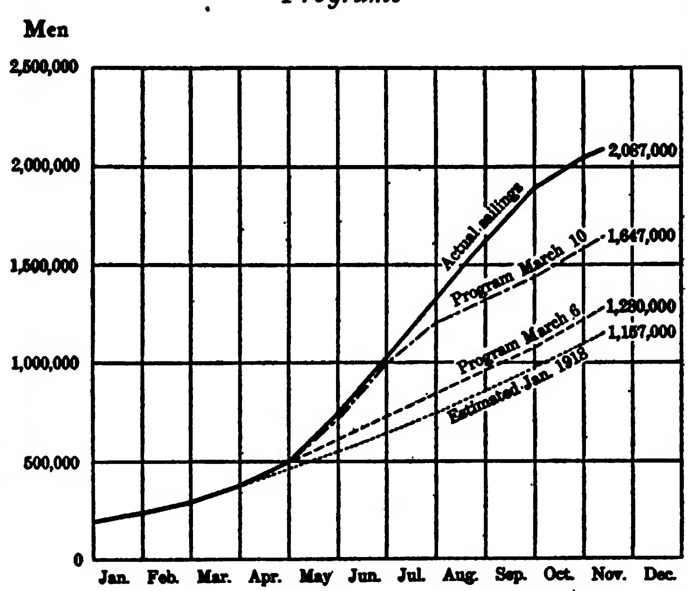
This agreement had a profound effect upon American production of munitions. Most important of all, it gave us time—time to build manufacturing capacity on a grand scale without the hampering necessity for immediate production; time to secure the best in design; time to attain quality in the enormous output to come later, as opposed to early quantity of indifferent class.

In the late autumn of 1917, shortly after Russia collapsed and withdrew from the war, it became evident that Germany would seize the opportunity to move her troops from the east-

ern front and concentrate her entire army against the French and British in 1918. This intelligence at once resulted in fresh emphasis upon the man-power phase of American coöperation. As early as December, 1917, the War Department was anticipating the extraordinary need for men in the coming spring by considering plans for the transport of troops up to the supposed limit of the capacity of all available American ships,

FIGURE 1

Actual Troop Sailings Compared with Programs



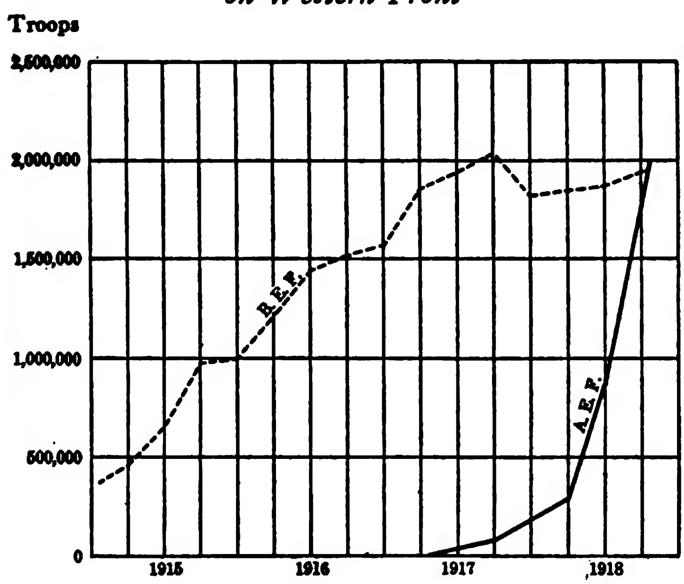
with what additional tonnage Great Britain and the other Allies could spare us. It is of record that the actual dispatch of troops to France far outstripped these early estimates.

Then came the long-expected German offensive, and the cry went up in Europe for men. England, her back against the wall, offered additional ships in which to transport six divisions over and above the number of troops already scheduled

for embarkation, agreeing further to feed and maintain these men for ten weeks while they were brigaded with British units for final training. After the six additional divisions had embarked there was still need of men, and the British continued their transports in our service. The high mark of shipment was reached in July, when 306,000 American soldiers were

FIGURE 2

British and American Expeditionary Forces on Western Front



transported across the Atlantic—more than three times the number contemplated for July in the schedule adopted six months earlier!

The effect of this stepping-up of the man-power program upon the shipment of supplies was described by Lieutenant Colonel Repington, the British military critic, writing in the *Morning Post* (London) on December 9, 1918, in part as follows:

. . . they [the British war cabinet] also prayed America in aid, implored her to send in haste all available infantry and machine guns, and placed at her disposal, to her great surprise, a large amount of transports to hasten arrivals. . . .

The American Government acceded to this request in the most loyal and generous manner. Assured by their Allies in France that the latter could fit out the American infantry divisions on their arrival with guns, horses, and transport, the Americans packed their infantry tightly in the ships and left to a later occasion the dispatch to France of guns, horses, transport, labor units, flying service, rolling stock, and a score of other things originally destined for transport with the divisions. If subsequently—and indeed up to the day that the armistice was signed—General Pershing found himself short of many indispensable things, and if his operations were thereby conducted under real difficulties of which he must have been only too sensible, the defects were not due to him and his staff, nor to the Washington administration . . . but solely to the self-sacrificing manner in which America had responded to the call of her friends.

The really amazing thing which America did was to place in France in nineteen months an army of the size and ability of the American Expeditionary Forces. The war taught us that America can organize, train, and transport troops of a superior sort at a rate which leaves far behind any practicable program for the manufacture of munitions. It upset the previous opinion that adequate military preparedness is largely a question of trained man power.

When the war touched us, our strategical equipment included plans ready drawn for the mobilization of men. There were on file at the Army War College in Washington detailed plans for defending our harbors, coasts, and borders. There were also certain plans for the training of new troops. It is worthy of note, however, that this equipment included no plan for the equally important and equally necessary mobilization of industry and production of munitions, which proved to be the most difficult phase of the actual preparation for war. The experience of 1917 and 1918 was a lesson in the time it takes to determine types, create designs, provide facilities, and establish manufacture. These years will forever stand as the most signal monument to the American genius of work-

shop and factory, which in this period ensured the victory by ensuring the timely arrival of the overwhelming force of America's resources in the form of America's munitions.

B. C. & R. F. W.

Washington, D. C.,
June, 1921.

PREFACE

MUCH of the text of this account of the production of American munitions during the World War was published by the War Department as the report of Benedict Crowell, the Assistant Secretary of War and Director of Munitions in the War Government. The authors of the report were four—the two who have signed this revision and Messrs. Robert J. Bulkley and Benjamin E. Ling, both of Cleveland. Mr. Bulkley, a former member of Congress, served in the War Department as a "dollar-a-year man." Mr. Ling was formerly a captain in the Construction Division, United States Army. In the preparation of the report the authors were assisted by about one hundred officers and civilian officials who compiled data and checked the accuracy of statement in the manuscript.

In substance, and to a considerable extent in text, this report has been embodied in the chapters that follow. Certain chapters, however, that dealt with subjects not strictly related to domestic munitions production have been dropped. When the original report was prepared, final production figures either did not exist or were of questionable accuracy. The statistical tables which appear in the present revision have been corrected in the light of later official information, and for the more important munitions items they tell the complete tale. Some few errors of fact inevitably crept into the original report. In so far as they have been brought to the attention of the authors, these mistakes have been corrected. Considerable new material has been added, notably the section dealing with the evolution of the War Department's internal organization during the war and those which summarize the activities of the Navy Department in the production of war vessels and supplies; an index has been supplied; and the whole text has been edited and somewhat rearranged.

THE ARMIES OF INDUSTRY

CHAPTER I

WAR DEPARTMENT ORGANIZATION

THE most important forward step taken in the manufacture of the supplies which were the fruition of the nation's whole industrial program during the World War was an act which might not ordinarily be considered a part of the production process at all. This step had nothing to do with machinery or materials, with designs or specifications, with labor or transportation. Yet it was as truly a part of the process of turning out guns, ammunition, and airplanes as were the procurement of machine tools and the erection of factory buildings. It was even more essential to the program than these tangible things; because, before the step was taken, we had spent many millions of dollars for ores, metals, machinery, and buildings, and the millions had apparently gone into a hole from which few supplies had issued. The great paraphernalia of manufacture with which the Government was providing itself, at such cost and with such effort, seemed to be a futile implement in our hands, unresponsive to all the driving force which the combined industrial talent of the country could put behind it—until, in a few quiet offices in Washington, there was brought about, somewhat tardily, to be sure, a relatively simple rearrangement of executive functions, a realignment of them, a creation of new channels for the flow of authority. And then, although there was little disturbance to the existing *personnel*, the reorganization of the business administration of the War Department made the industrial equipment effective at last and brought success out of failure. The part it played in bringing about the fall of the German Empire has perhaps not been justly estimated.

It is given to only a few men to have executive part in great

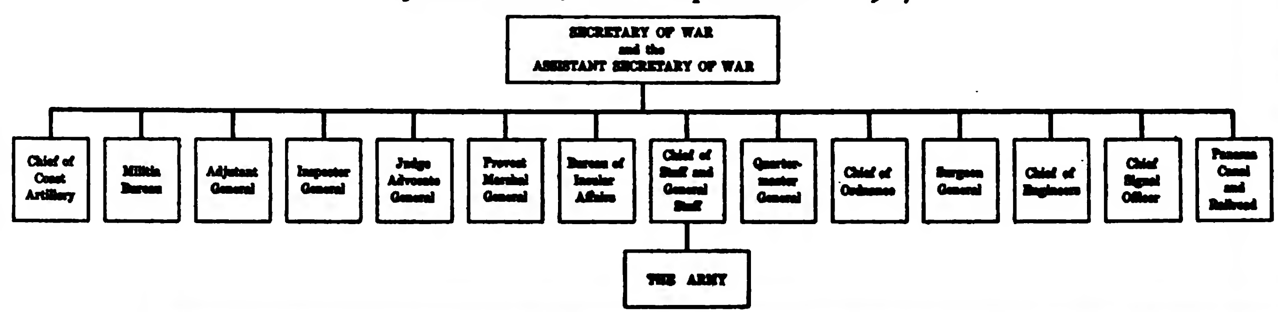
affairs. A good half of the people of the United States are engaged in individual enterprises—they are farmers, lawyers, doctors, storekeepers—and nine-tenths of the rest are cogs in big machines, not only unconcerned with the intricacies of management, but sometimes even contemptuous of them. Some of our so-called advanced thinkers hold that the cogs are, after all, the important things in the machine—once you turn on the power the thing will run of itself. "Let the directors in New York solemnly meet and agitate themselves with their organization schemes in the delusion that they are producers and valuable members of society,"—so runs the modern argument,—"but what do they know about industry and production? The real worker, the man who keeps the wheels turning, is the man out there on the job; and things would run along pretty much the same if all the executive offices in the world were wiped out at once. Industry would go right ahead producing necessities at its same rate and with no loss of efficiency."

If there be readers of this book who entertain such views, their attention is invited to an adjoining chart (Figure 3) which shows the organization of the War Department from the declaration of war in the spring of 1917 until January, 1918. It will be noted that up to the date last mentioned fourteen administrative bureaus reported directly to the Secretary of War. This meant that fourteen different kinds of sets of problems came up to him for decision and action. Now, this may have been a possible arrangement during the time of peace. But when the war came to expand the business of some of these bureaus as much as twenty times, it became physically impossible for one man to look after so many affairs.

"But what of it?"—again we are paraphrasing our serious thinkers—"Everybody knows that the Secretary of War is a figurehead anyhow—usually a lawyer who knows nothing about the science of making war, but who is put in there to act as a sort of official yes-man to give legal authenticity to the acts of the bureau chiefs, who are the real organization and who know their jobs and know how to keep

FIGURE 3

Organization of War Department in 1917



things running from one administration to another. Fourteen bureaus? What difference did it make—fourteen, or two dozen, or fifty? As long as the Secretary of War could avoid writer's cramp everything would be all right, wouldn't it? The bureaus themselves would know how to conduct their own business."

The complete answer to these questions was found in the condition of our war program in December, 1917. To those in Washington, that month brought the darkest days of the war. The various war department bureaus had indeed known their jobs, and known them only too well. As their business expanded, as it became less and less possible to apprise the Secretary of War of what they were doing, they grew out of touch with the executive direction which was supposed to exist; and each production bureau in its own province of industry became virtually a sovereign potentate, unchecked, uncontrolled. They knew their work only too well, and that work was to produce the supplies for which each was charged with responsibility, and to get those supplies to France. In that direction lay success. And since it soon became evident that the industry and transportation of the country were not going to be sufficient to allow every bureau to satisfy its ambitions to the full, the proper tactics for the bureau chief were to get his program through first and let the others look out for themselves.

It was not as if only one or two bureaus adopted this attitude: every single bureau responsible for producing supplies for the Army conducted its affairs in just this spirit of competition. There were five such bureaus at first, and eight later on, scarcely one of which but was prosecuting a business greater than that of the War Department as a whole before the declaration of war. There was in the War Department's organization nothing that could put an effective curb upon their individualistic operations. Six months of this sort of thing brought the inevitable consequences which any good business man could have foreseen from the start. The crisis came in December, 1917.

Nature itself that year seemed to share in the hostility of the other inanimate forces which the Government had found it impossible to control; for the winter descended with a ferocity that will make the season remembered long for that reason alone. But there were other things besides the ice and the blizzards to make the outlook bleak for the officials in Washington. The munitions program was approaching a state of paralysis. Certain factories were loaded with contracts far beyond their ability to obtain materials, labor, transportation, or new factory facilities. In like manner certain whole manufacturing districts were so overloaded with war business that their utmost in facilities, labor, fuel, transportation, and power was entirely inadequate to the handling of the contracts in any reasonable time. And while in these districts there was great labor scarcity, and while projects were being delayed as a consequence, in other districts not so attractive to the competing war bureaus there was actual unemployment both of men and of facilities.

The congestion of war business within certain districts was a heavy contributing cause of the fuel shortage that nearly disrupted industry in those weeks. The unwise concentration of contracts also resulted in shortages in electric power in these districts. Every bureau dispatched its finished products to the ports as rapidly as it succeeded in procuring them. There the port officers had to take into consideration the balanced lading of vessels and also the immediate and more pressing needs of the A. E. F., for the available tonnage was scant. Consequently, they were unable to ship many of the materials reaching the ports. Army freight choked the ports and, backing up, clogged the rails so far back from tidewater that freight transportation for a time almost altogether ceased.

The public began to hear rumors of serious failures in the program of supply. Some of the troops taken by the draft and concentrated in cantonments found themselves compelled to drill with dummy rifles made of wood instead of with real guns. This was bad enough; but worse was the fact that in the camps existed shortages in clothing, in hospital equipment,

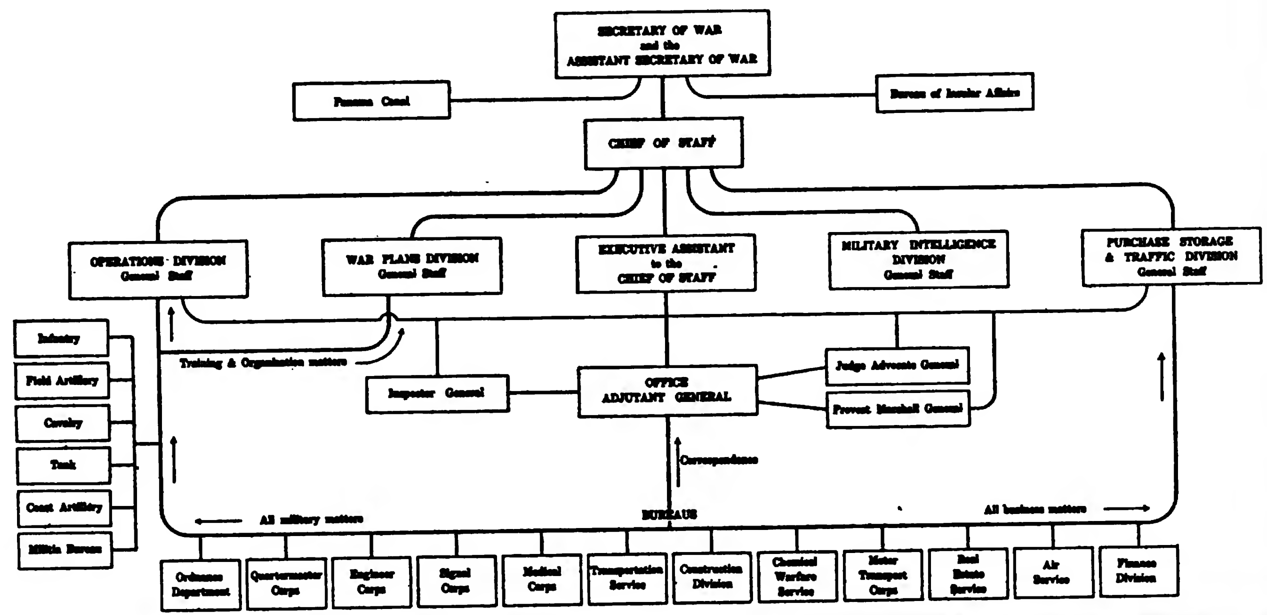
and in other supplies. Pneumonia became epidemic in some of the camps, and it was openly charged that the failure of the War Department to provide sufficient clothing and shelter for the troops was primarily responsible for the deaths which resulted. Because of the railroad congestion and the shortage in fuel, all but the most essential manufacturing operations suffered a partial suspension, and the civil population shivered on a reduced ration of coal. Food supplies grew short. Ocean ships, unable to secure bunker coal promptly in our ports, were unable to operate efficiently. The whole world was aware that the Germans were planning a sinister and final military drive in the spring of 1918; and while we were doing all we could to send men to France to meet that contingency, there was in official quarters an apprehension that we might not be able to support our overseas troops and those of the Allies with food and other essential supplies.

That was what the original organization of the War Department did to the war program. That was the factory trying to run itself without overhead direction and control. The War Department went along in this fashion for about eight months after the declaration of war, and then it found that one of two things had to happen: either its whole industrial program would go to smash and it would stand forth as a confessed and notorious failure, or it must reorganize. It chose to reorganize, and it began its reorganization only just in the nick of time. That reorganization was the profoundest change in the War Department in modern times; and, as we have said before, it was the most important thing that could have happened in the production of our army supplies. The reorganization began about January 1, 1918.

The accompanying chart (Figure 4) shows what occurred. In the first place, what is made apparent by a comparison of the two charts is the ostensible rise of the General Staff in power. Originally the General Staff existed on a plane of authority with the principal bureaus of the War Department. Although theoretically it was supposed to be the planning and coördinating agency of the Army, before the spring of 1917 it had

FIGURE 4

Organization of War Department in 1918



never been able actually to wrest much authority away from the principal bureaus. But in the first months of the war the General Staff had succeeded in asserting its power. By degrees, yet swiftly, it had assumed jurisdiction over the raising and training of armies; it had gained, in fact, complete charge of the organization and movement of the Army until it reached Europe, after which the troops came under the command of the organization of the American Expeditionary Forces.

The significant fact of the reorganization, the abrupt and revolutionary development, is indicated at the extreme right of the chart (Figure 4). For the first time in the official set-up of military functions, the industrial side of waging war is accorded its due weight—is placed on an equality with the function of supplying trained troops to the field commander. For the first time, too, the scattered, but huge, activities of the War Department in the procurement of supplies are concentrated and included within a single overhead business organization, the Division of Purchase, Storage, and Traffic, to which the former autocratic and independent supply bureaus have become subsidiary. The Division of Purchase, Storage, and Traffic is now the central overhead purchasing agency of the War Department, supreme in everything that pertains to the effective overhead control and coördination of the industrial enterprises of the War Department. This, to be sure, is control and coördination only, but with the effectiveness of law behind it. The individual supply bureaus, now virtually departments of the Division of Purchase, Storage, and Traffic, still, but in line with the instructions of the overhead organization, create their designs, write their contracts, and otherwise attend to the concrete acts of procurement.

Had this organization or a similar one been put in control at the time war was declared, many of the most acute economic embarrassments which afflicted the United States during the war would never have occurred. War industry would have proceeded with sanity and singleness of purpose instead of as a collection of competitors resembling traders battling in the wheat pit. The proof of this statement lies in the fact that the

new organization, coming late as it did, at a time when it seemed almost as if no human power could rescue the supply situation, actually and in the face of the most adverse conditions of weather, fuel supply, and transportation, brought the War Department's industry to order and made creditable its performance in the first ten months of 1918.

In characterizing the change in the organization of the War Department we have used the word "abrupt"; but from this it is not to be inferred that the reorganization was accomplished suddenly. The plan for the reorganization was worked out abruptly,—it was worked out during those days of December when it was evident that the existing organization must either reform or go to pieces,—but to plan the reorganization was far easier than to put the plan into effect. The War Department had to be kept as a going concern even while it was changing its internal structure. While the Department was setting its house in order, there could be no relaxation of the pressure upon the producers of supplies. There were, moreover, internal difficulties in the way of rapid reorganization—efficient elements to be retained and worked into the new scheme, legal obstacles to be hurdled (for all of the reorganization had to keep within the strictures of existing law), and the capabilities of various executives had to be taken into consideration. In fact, because of the conditions, the War Department was forced to lean heavily upon individual men; and whenever an officer showed extraordinary ability as an executive the reorganization was so conducted as to give him extraordinary powers to administer. The reorganizers were dealing with conditions rather than theories, and they built up their plans to take the utmost advantage of things as they were. It follows that the reorganization was nothing that could be put through in a day. The Division of Purchase, Storage, and Traffic was not brought formally into existence until April, 1918, although for weeks before that time the most important activities in the central control of war department industry were in full and effective operation, and the industrial situation began to revive immediately. Not until

the autumn of 1918 was the reorganization complete in every detail.

Since the reorganization had to keep within the law, the central business office of the Department, the Division of Purchase, Storage, and Traffic, had to be given a military status. Its officers had to be commissioned in the Army, and the Division itself had to be fitted somewhere into the military organization. There was no legal authority for placing it directly under civilian control. It should be remembered that this whole plan was formulated and largely carried out before the passage of the Overman Act, which gave the President blanket powers to rearrange the Government in any way he saw fit. Had the Overman Act antedated the reorganization of the War Department, it is possible that the overhead business office of the Department would have been made a civilian agency through and through. But there was no Overman Act; the only war department branch which had any legal right to coördinate and control the activities of the other branches was the General Staff; and therefore to the General Staff the new control agency, the Division of Purchase, Storage, and Traffic, was attached.

This necessity gave to the General Staff (see Figure 4) an appearance of power which it did not actually possess. In the chart the General Staff itself, through its Division of Purchase, Storage, and Traffic, has apparently become the great procuring agency of the War Department, in addition to its purely military functions. This, however, was only an arrangement *pro forma* to give authenticity to the acts of the Division of Purchase, Storage, and Traffic. Actually, a different arrangement was in effect.

The ancient office of Assistant Secretary of War had long been more or less of a political sinecure—a place of considerable honor, but almost without practical value or responsibility. The office had become an eddy into which had drifted a few incidental and inconsequential functions of the War Department, none of them directly related to the business of waging war. It characterizes the office to say that its principal

duty had been administering the national cemeteries. When things began to go wrong with the war industrial program, the Secretary of War saw in this unused office the opportunity to give to the War Department the thing which it then most sorely needed—industrial ability at the top of its organization. In November, 1917, he called to the office a man whose training and experience had been entirely in the industrial field and turned over to his administration all the industrial activities of the War Department—gave to him literally a blanket commission to rescue our war industry from the plight into which it had fallen. The Division of Purchase, Storage, and Traffic was thereupon plotted as the agency through which the Assistant Secretary, to whom later was also given the title "Director of Munitions," could gain control of the industry. Thereafter the Assistant Secretary of War was the industrial head of the War Department. But since this arrangement was one of agreement rather than of law, the executive decisions of the Assistant Secretary went down to the Division of Purchase, Storage, and Traffic as from the Secretary of War, through the technically legal channel of the General Staff. In spite of appearances, therefore, the General Staff remained a purely military body. The Chief of Staff was the Secretary of War's military adviser: the Assistant Secretary was the Secretary of War's industrial adviser.

This explanation will make clear to anyone with a knowledge of military organization a situation at once puzzling and outwardly improper. Even a number of experts within and outside the War Department, taken in by appearances during the war, criticized the General Staff for its alleged assumption of the powers of procurement. Of course, no general staff of any army ever before attempted to turn itself into an agency of procurement. Nor did our General Staff do that, actually. Its administration of procurement was only a perfunctory one. The actual administration was always in the hands of men whose training was industrial.

The reorganization of the General Staff was being studied and worked out in December, 1917, but it was evident that

we could not wait for the gradual upbuilding of that body. For eight months the whole War Department had been drifting along without a rudder. No one was directing—no one was doing any thinking in a large way. The work of the War Department was not being properly coördinated with that of other important war-making agencies, such as the Navy, the Shipping Board, and the War Industries Board. Immediate measures were necessary to prevent the failure then so imminent. No attention was being given to general policies. Definite plans were entirely lacking. No major programs had been worked out. No large industrial plans could be laid until the extent of our military participation was decided. Our military plans depended upon our ability to transport men and munitions to Europe. This meant shipping. The amount of shipping that could be allocated to our transatlantic transport fleets depended largely upon how much tonnage we could withdraw from the fleets which were supplying our industry with raw materials. Withdrawing tonnage from industry meant decreasing our importations of iron ore, manganese ore, chrome, nitrates, sugar, and other important commodities, and curtailing our water shipments of coal, on which New England so largely depended. The withdrawal of ships from these trades would cripple our war industries. How much tonnage could we afford to withdraw from commerce in favor of military transport? That depended upon our military program. And there was no military program.

These and many other questions had to be settled without further delay. It was obvious that what was needed was a small body of men, men with time to think, placed at the head of the War Department to work out programs and compose and harmonize divergent, but pressing, interests. We could not afford to drift any longer. The solution was the creation of the War Council—a temporary expedient to bridge over the time required for the reorganization of the General Staff. Theoretically the War Council was merely an advisory body, without authority. However, the Secretary of War, the Assistant Secretary of War, and the Chief of Staff were members

Photo by U. S. Army Air Service

MUNITIONS AND NAVY BUILDINGS, WASHINGTON, D. C.

Photo from Ford Motor Company

MAKING LIBERTY ENGINE CYLINDERS

Photo by International Film Service

THE WAR COUNCIL

From left to right: Mr. Day, General Crozier, General Weaver, General Bliss, Secretary Baker, Assistant Secretary Crowell, General Crowder, General Pierce, Colonel U. S. Grant, 3d (Recorder)

of it; and therefore its decisions were promptly carried out. It thus had real power to act.

It is worth while to pause a moment to examine this body about which so little has been published or said. Besides the officers named above, its members were: Major General William Crozier, Major General E. M. Weaver, Major General E. H. Crowder, Major General Henry G. Sharpe, Major General George W. Goethals, Brigadier General Palmer E. Pierce, Mr. Charles Day, and Mr. E. R. Stettinius. The first meeting of the War Council, a meeting devoted to organizing, was held December 19, 1917; and at this meeting the Secretary of War outlined the functions of the War Council in substance as follows:

The most important contribution toward the victorious completion of the war was brains in the conduct of it. . . . The members of the War Council were expected to keep in close touch with the situation in Europe, and for that purpose at least one member of the Council should be constantly absent in Europe getting information for its guidance. . . . It was essential for the Council to be a thinking body, and for this purpose to keep itself free from detail. . . . It should give special attention to the question of coördination of matters relating to the supplies for the Expeditionary Forces in France. . . . Consideration should be given each day to General Pershing's cablegrams. . . . Broad questions relating to the ports of embarkation should be considered. . . . The Secretary of War invited from the Council the freest initiative in the suggestion of fresh ideas. . . . He hoped and expected to receive from the Council any suggestions that tended toward securing final success. . . . For all these reasons he considered the Council the most important body in the War Department. . . . All information in the War Department and in other government departments would be given to the War Council. . . .*

Under such auspices the War Council set to work with a will, meeting every morning; and gradually it saw order

* Digested from the minutes of the War Council.

evolved out of chaos. Most of its members gave their entire time to the work of the Council. Thus they were freed from the details of administration and became able to visualize the war effort as a whole. For the first time since the declaration of war there was a discussion of complete programs. In these daily conferences first developed the realization of the need eventually filled by the creation of the Shipping Control Committee; and the Shipping Control Committee, after its formation, met with the War Council every Wednesday, in a session which was given over to consideration of the shipping situation and in which the shipping problems were frankly discussed and settled across the table without delay. To these Wednesday shipping meetings came also the Secretary of the Navy, Mr. Baruch (the chairman of the War Industries Board), Mr. Hurley (the chairman of the Shipping Board), Mr. Schwab (the director-general of the Emergency Fleet Corporation), Mr. McCormick (the chairman of the War Trade Board), and others.

At its second meeting, on December 20, the War Council got down to business, discussing questions arising in the administration of the draft and taking up the advisability of merging all the divisions of the Regular Army, National Guard, and National Army into a single Army of the United States. The first steps were taken toward getting together that mass of information from which was worked out our military program. The discussion on this theme led to the prompt creation (in February and March, 1918) of the Statistics Branch of the General Staff.

From first to last the War Council considered all sorts of questions relating to the conduct of the war; but it was never more than temporarily diverted from its main task—that of formulating and adopting a comprehensive military program. After all the necessary figures and other data had been collected, studied, and digested, the program was outlined, taken to the President for his approval, approved by the President, and formally adopted. Thereafter the War Council was kept busy considering changes in the program made necessary by

the ever shifting conditions in Europe during the first six months of 1918, and in investigating and strengthening what seemed to be the weak spots. The War Council held daily meetings until May 1, 1918. From then until July the meetings were not so frequent, and from July to the armistice only the Wednesday shipping meetings continued to be held.

The vindication of the usefulness of the War Council, of the fact that it filled an important place in the administration of the War Department, came after the armistice. Congress, in reorganizing the War Department in conformity with the lessons learned during the war, created a permanent War Council, which exists to-day, ready to fulfill its part in the event of another emergency. Such an overhead planning body would have been of invaluable service, had it been created at the outbreak of the war in 1917, since we would have had from it an early solution of problems which under the old procedure hampered the war program for many months.

The original reorganization of the War Department persisted for a year and a half after the armistice, the Division of Purchase, Storage, and Traffic—still attached to the General Staff—dealing with the numerous industrial problems that arose in the course of the demobilization. But as the War Department's business dwindled in volume and once more approached the normal, the time came to place the Department upon the permanent peace footing. It was a time to apply the lessons learned during the war, when the scars of old mistakes were still red and smarting. The old independent bureau system had been an egregious failure during the Spanish-American War, but the country had not been wise enough after that brief conflict to apply the lesson and correct the organization before the World War. To repeat that error was unthinkable; and in the spring of 1920, as a measure in future preparedness, Congress took steps to give the War Department a permanent supply organization that could function effectively in the event of war.

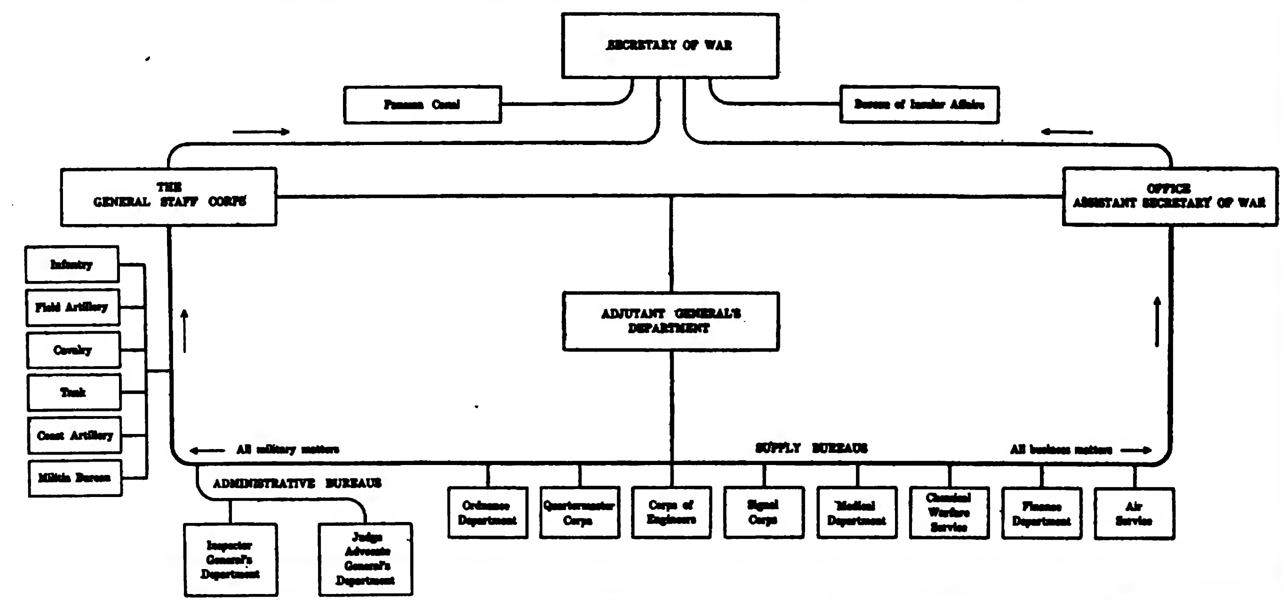
The question was whether to preserve the organization adopted during the war or to provide something different and

better. It was found to be no easy thing to make a change, for some of the highest officials of the General Staff had begun to take themselves seriously as producers of military supplies—shutting their eyes to the fact that the inclusion of the Division of Purchase, Storage, and Traffic within the General Staff had been only a measure of legal expediency—and urged the retention of the 1918 plan permanently. Since the arrangement which made the Assistant Secretary of War the director of the manufacturing enterprises had no legal foundation, it followed that, if the war organization were perpetuated in law as the peace organization, the General Staff was bound to become supreme in questions of producing supplies, and that the control of the Assistant Secretary over these affairs would depend each time upon the ability and aggressiveness of the Assistant Secretary who chanced to be in office.

From the standpoint of good organization, any assumption by the General Staff of control over the production of supplies is fundamentally wrong, and in a great emergency it might prove to be as disastrous as the attempted operation of the War Department by its independent bureaus. To be sure, the General Staff is concerned with the production of supplies, and vitally so—as much concerned as it is with problems in *personnel*. The General Staff is the Army's great advisory and coördinating agency, and therefore the supply problems properly fall within its jurisdiction. Its interest in these problems, however, is military rather than industrial—a distinction which many staff officers were unable to grasp. The range of supplies to be produced, the quantities of them, and the distribution of the finished supplies are affairs in which the General Staff should be supreme. It should even dictate specifications with the understanding that the specifications are military specifications and not manufacturing specifications. It can if it likes call for the production of airplanes with a speed of 200 miles an hour, or of field guns that can shoot 50 miles, but the moment it attempts to design these materials and to procure their manufacture, then it trespasses in a field not properly its own.

FIGURE 5

Organization of War Department under Act of June 4, 1920



When the War Department approaches industry with demands for production on a modern war-time scale, to be effective it must deal with industry on a practical industrial basis. It must speak the language of the tribe. This the general staff officer is not fitted to do. His whole training has been in another field. A Chief of Staff must be a man of great military experience, one who has spent his life in military affairs. To expect him to be also a successful administrator of war industry is to expect too much. He is no more fitted by experience for such work than a Presbyterian synod is qualified to promote a prize fight.

This view prevailed in Congress, and the permanent reorganization law of June 4, 1920, as indicated in our Figure 5, recognized the dual function of waging war—the military function and the industrial. Before the World War the production of munitions was supposed to be merely incidental to the larger project of raising an army and maneuvering it at the front. It took the experience in France to demonstrate to us that wars have become as much industrial as military and that a nation at war is only as strong as its industry. The reorganization law set up the Assistant Secretary of War as the industrial head of the War Department and added appreciably to his salary, so that the office, with its great responsibilities, might attract from industry men of ability. In any estimate of the military assets which the World War provided for the United States, the fact should not be overlooked that, as long as the present law stands, we have in the War Department an organization which should enable war industry to proceed effectively from the first minute of our belligerency. To change from a peace to a war footing, all that will be necessary is to increase the number of workers in the office of the Assistant Secretary of War, as the expanding program demands the services of sub-executives.

That this is the correct theory of organization for the War Department was stated unequivocally by a most able and expert authority, a man not unacquainted with the working of the Department:

. . . to prepare the country to meet a state of war with honor and safety, much must depend on the organization of our military peace establishment. . . . To give such an organization, the leading principles in its formation ought to be that at the commencement of hostilities there should be nothing either to new model or to create. The only difference, consequently, between the peace and war formation . . . ought to be in the increased magnitude of the latter; and the only change in passing from the former to the latter should consist in giving to it the augmentation which will then be necessary.

These words were not written with the lesson of the World War fresh in mind, as they might seem to have been. They were the words of John C. Calhoun, the Secretary of War in President Monroe's cabinet, in his annual report for the year 1820. A century later we have written those principles into law—but not before going through a costly experience in disregarding them.

CHAPTER II

THE ORDNANCE PROBLEM

TO arm the manhood called to defend the nation in 1917 and 1918, to make civilians into soldiers by giving them the tools of the martial profession—such was the task of the Ordnance Department in the late war.

The casual mind may define ordnance as artillery alone. It will surprise many to learn that in the American ordnance catalogue of supplies during the recent war there were over 100,000 separate and distinct items. Thousands of the items of ordnance were distinctly noncommercial; that is, they had to be designed and produced specially for the uses of war.

Although the principles of fighting have changed essentially not one whit since the age when projectiles were stones hurled by catapults, nearly every advance in mechanical science has had its corollary in warfare, until to-day the weapons which man has devised to destroy the military power of his enemy make up an intricate and imposing list. When America accepted the challenge of Germany in 1917, part of the range of ordnance had already been produced in moderate quantities in the United States, part of it had been developed by the more militaristic nations of the world in the last decade or quarter century, and part of it was purely the offspring of two and one-half years of desperate fighting before America entered the great struggle. Yet all of it, both the strange and the familiar, had to be put in production here on a grand scale and in a minimum of time, that the American millions might go adequately equipped to meet the foe. Let us examine the range of this equipment, seeing in the major items something of the caliber of the problem which confronted the Ordnance Department at the outset of the great enterprise.

To begin with the artillery: First in order of size there was the baby two-man cannon of 37 millimeters (about an inch and a half) in the diameter of its bore—a European development new to our experience, so light that it could be handled by foot troops in the field, used for annihilating the enemy's machine gun emplacements. Then came the mobile field guns: the famous 75, the equivalent in size of our former 3-inch gun; the 155-millimeter howitzer; the French 155-millimeter G. P. F. (Grand Puissance Filloux) gun of glorious record in the war, and its American prototypes, the 4.7-inch, 5-inch, and 6-inch guns—all of these employed to shell crossroads and harass the enemy's middle area. Beyond these were the 8-inch and 9.2-inch howitzers and the terrific 240-millimeter howitzer, for throwing great weights of destruction high in air, to descend with a plunge upon the enemy's strongest defenses. Then there were the 8-inch, 10-inch, 12-inch, and 14-inch guns on railway mounts, for pounding the depots and dumps in the enemy's back areas. These weapons were so tremendous in weight when mounted as to require from 16 to 24 axles on the car, to distribute the load and the recoil of firing within the limits of the strength of standard heavy railway track.

All these guns had to be produced in great numbers, if the future requirements of the American forces were to be met; produced by thousands in the smaller sizes and by hundreds and scores in the larger.

And these weapons would be ineffective without adequate supplies of ammunition. For the mobile field guns this meant a requirement of millions of shell or shrapnel, to sustain the incessant bombardments and the concentrated barrages which characterized the great war. The entire weight of projectiles fired in such an historic engagement as Gettysburg would supply the artillery for only a few minutes in such intensive bombardments as sowed the soil of Flanders with steel.

The artillery demanded also an immense amount of heavy equipment—limbers, caissons, auto ammunition trucks, and tractors to drag the heavy and middle-heavy artillery. Some

of these vehicles were fitted with self-propelled caterpillar mounts which could climb a 40-degree grade or make as high as twelve miles an hour on level ground. These, the adaptations to warfare of peaceful farm- and construction-machine traction, for the first time rendered the greater guns exceedingly mobile, enabling them to go into action instantly upon arrival and to depart to safety just as soon as their mission was accomplished.

Then, too, this artillery equipment had to have adequate facilities for maintenance in the field, and this need brought into existence another enormous phase of the ordnance program. There had to be mobile ordnance repair shops for each division, consisting of miniature machine shops completely fitted out with power and its transmission equipment and mounted directly on motor trucks. There had to be semi-heavy repair shops on 5-ton tractors, these to be to the corps what the truck machine shop was to the division. Each army headquarters called for its semi-permanent repair shop for artillery and still larger repair shops for its railway artillery.

And in addition to all these there were the base repair shops in France, erected on a scale to employ a force three times as large as the combined organizations of all the manufacturing arsenals of the United States in time of peace. These shops had a capacity for relining 1,000 cannon and overhauling and repairing 2,000 motor vehicles, 7,000 machine guns, 50,000 rifles, and 2,000 pistols every month. This equipment of artillery and its maintenance organization implies the flow from American industry of enormous quantities of repair parts and spare parts to keep the artillery in good condition.

Coming next to the more personal equipment of the soldier, we find the Ordnance Department confronted by the necessity of manufacturing shoulder rifles by the million and cartridges for them by the billion. The World War brought the machine gun into its own, requiring in the United States the manufacture of these complicated and expensive weapons by tens of thousands, including the one-man automatic rifle, itself an arm of a deadly and effective type.

Simultaneously with the mass employment of machine guns in the field came the development of the modern machine gun barrage, the indirect fire of which required sighting instruments of the most delicate and accurate sort, and tripods with finely calibrated elevating and traversing devices, so that the gunner might place the deadly hail safely over the heads of his own unseen advancing lines with maximum damage to the enemy. And the thousands of machine guns required water jackets to keep their barrels cool and specially built carts for carrying them.

The personal armament of the soldier also called for an automatic pistol or a revolver for use in the infighting, when squads came in actual contact with soldiers of the enemy. These had to be produced by hundreds of thousands. The requirements of the field demanded hundreds of thousands of trench knives—murderous blades backed by the momentum of heavily weighted handles, which in turn were protected by guards embodying the principle of the thug's brass "knucks" armed with sharp points. Then there were the special weapons, largely born of modern trench warfare. These included mortars, ranging from the small 3-inch Stokes, light enough to go over the top and simple enough to be fired from between the steadying knees of a squatting soldier, to the great 240-millimeter trench mortar of fixed position. The mortars proved to be exceedingly effective against concentrations of troops; and there was devised for them a great variety of bombs and shell, not only of the high-explosive fragmentation type, but also of types containing poison gas or fuming chemicals. Great quantities both of mortars and of their ammunition were required.

From the security of the trenches the soldiers first threw out grenades, which burst in the enemy's trenches opposite and created havoc. From the original device were developed grenades of various sorts—gas grenades for cleaning up dugouts, molten-metal grenades for fusing the firing mechanisms of captured enemy cannon and machine guns, paper grenades to kill by concussion. Then there were the rifle grenades, each

to be fitted on the muzzle of a rifle and hurled by the lift of gases following the bullet, which passed neatly through the hole provided for it. The production of grenades was no small part of the American ordnance problem. In addition to these trench weapons were the Livens projectors, which, fired in multiple by electricity, hurled a veritable cloud of gas containers into a selected area of enemy terrain, usually with great demoralization of enemy forces. Bayonets for the rifles, bolos, helmets, periscopes for looking safely over the edges of the trenches, panoramic sights, range finders—these are only a few of the ordnance accessories of general application.

Then there were those innovations of the great war, the tanks—the 3-ton "whippet," built to escort the infantry waves; the 6-ton tanks, most used of all; and the powerful Anglo-American heavy tanks, each mounting a 37-millimeter cannon and four machine guns.

The war in the air put added demands upon ordnance. It required the stripped machine gun which fired cartridges so rapidly that their explosions merged into a single continuous roar, yet timed each shot so nicely that it passed between the flying blades of the propeller. There had to be electric heaters for the gun mechanisms to prevent the oil which lubricated them from becoming congealed in the cold of high altitudes. The airplane gun required armor-piercing bullets for use against armored planes, incendiary bullets to ignite the hydrogen of the enemy's balloon or to fire the gasoline escaping through the wound in the hostile airplane's fuel tank, and tracer bullets to direct the aim of the aërial gunner. Other equipment for the airman included shot counters, to tell him instantly what quantity of ammunition he had on hand, and gun sights, ingeniously contrived to correct his aim automatically for the relative speed and direction of the opposing plane. These were all developments in ordnance brought about by the World War, and each involved problems for the production organization to solve.

Then there were the drop bombs of aërial warfare, of many gradations in weight up to 500 pounds each, these latter ex-

perimental ones forecasting the day when bombs weighing 1,600 pounds would be dropped from the sky; then bomb sights to determine the moment when the missile must be dropped in order to hit its target, sights which corrected for the altitude, the wind resistance, and the rate of speed of the airplane; and then mechanisms to suspend the bombs from the plane and to release them at the will of the operator.

The list might be stretched out almost indefinitely—through pyrotechnics, developed by the exigencies in Europe into an elaborate system; through helmets and armor, revivals from medieval times to protect the modern soldier from injury; through the assortment of heavy textiles, which gave the troops their belts, their bandoleers, their haversacks, and their holsters; through canteens, cutlery for the messes in the field, shotguns, and so on. There might be set down thousands of items of the list which we know as modern ordnance.

It will be noted that the most important articles in this range are articles of a noncommercial type. In other words, they are not the sort of things that the industry of the country builds in time of peace, or learns how to build. Many other war functions came naturally to a country skilled in handling food supplies for teeming populations, in solving housing problems for whole cities, and in managing transportation for a hundred million people; there was at hand the requisite ability to conduct war enterprises of such scope smoothly and efficiently. But there was in the country at the outbreak of war little knowledge of the technique of ordnance production.

The declaration of war found an American Ordnance Department whose entire commissioned *personnel* consisted of ninety-seven officers. Only ten of this number were experienced in the design of artillery weapons. The projected army of 5,000,000 men required 11,000 trained officers to handle every phase of ordnance service. To be sure, a portion of this production would have to do with the manufacture of articles of a commercial type, such as automobiles, trucks, meat cans, mess equipment, and the like; yet the ratio of 97 to 11,000 gives an indication of the amount of ordnance knowledge possessed

by the War Department at the outbreak of war as compared to what it would need to equip the first 5,000,000 men for battle.

The Government could obtain commissary officers from the food industry; it could turn bank tellers into paymasters, convert builders into construction quartermasters, find transportation officers in the great railway systems, Signal Corps officers in the telegraph companies, medical officers in professional life. But there was no broad field to which ordnance could turn to find specialized skill available. The best it could do was to go into the heavy manufacturing industry for expert engineers who could later be trained in the special problems of ordnance.

Prior to 1914 there were but six government arsenals and two large private ordnance works which knew anything about the production of heavy weapons. After 1914 war industry sprang up in the United States; but in 1917 there were only a score or so of firms engaged in the manufacture of artillery ammunition, big guns, rifles, machine guns, and other important ordnance supplies for the Allies. When the armistice was signed, nearly 8,000 manufacturing plants in the United States were working on ordnance contracts. It is true that many of these contracts entailed production not much dissimilar to commercial output; yet here is another ratio—the twenty or more original factories compared with the ultimate 8,000—which serves to indicate the expansion of our industrial knowledge of the special processes incident to ordnance manufacture.

When we found ourselves in the war, our first step was to extend our ordnance knowledge as quickly as possible. The war in Europe had developed thousands of new items of ordnance, many of them carefully guarded as military secrets, with which our own officers were familiar in only a general way. As soon as we became a belligerent, we at once turned to the Allies, and they freely and fully gave us of their store of knowledge—plans, specifications, working models, secret devices, and complete manufacturing processes. With this knowledge at hand, we adopted for our own program certain French

FIGURE 6

Expenditure of Artillery Ammunition in Modern Battles

Year	*Battle*	*Days' duration*	*Army*	*Rounds of artillery ammunition expended*
1863	Chickamauga	2	Union	7,325
1863	Gettysburg	3	Union	32,781
1870	St. Privat	1	German	39,000
1904	Nan Shan	1	Japanese	34,047
1904	Liao Yang	9	Russian	134,400
1904	Sha Ho	9	Russian	274,360
1915	Neuve Chapelle	[1] 3	British	197,000
1915	Souchez	[2] 1	French	300,000
1916	Somme	[3] 7	British	4,000,000
1917	Messines Ridge	[3] 7	British	2,753,000
1918	St. Mihiel	[2] 4	United States	1,093,217

[1] Artillery preparation lasted 35 minutes. [2] Artillery preparation lasted 4 hours.
[3] Artillery preparation intermittent 7 days.

One of the most striking developments of the recent war was the great increase in the use of artillery to precede infantry action in battle. This is illustrated by a comparison of the expenditure of artillery ammunition in characteristic battles of past wars with that in important battles of the war just ended. The special features of the several battles should be kept in mind. Chickamauga was fought in a heavily wooded region; Gettysburg and St. Privat over open farm land. The latter battles, together with Nan Shan, and all the battles of the World War considered above, involved artillery preparation for assault upon armies in defensive position. The expenditures, therefore, are roughly comparable.

The high mark of the use of artillery in offensive battle was reached at the Somme and Messines Ridge, before the effective use of tanks was developed.

types of field guns and howitzers and British types of heavy howitzers. The reproduction of the British types caused no unusual difficulties; but the adoption of French plans brought into the situation a factor the difficulties of which are apt not to be appreciated by the uninitiated. This new element was the circumstance that the entire French system of manufacture in metals is radically different from our own in its practices and is not readily adapted to American methods.

The English and the American engineers and shops use inches and feet in their measurements, but the French use the metric system. This fact means that there was not a single standard American drill, reamer, tap, die, or other machine-shop tool that would accurately produce the result called for by a French ordnance drawing in the metric system. Moreover, the French standards for metal stocks, sheets, plates, angles, I-beams, rivet holes, and rivet spacing are far different from American standards.

It was discovered that complete French drawings were in numerous cases nonexistent, the French practice relying for small details upon the memory and skill of the artisans. But even when the complete drawings were obtained, the American ordnance engineer was confronted with the choice of either revolutionizing the machining industry of the United States by changing over its entire equipment to conform to the metric system, or else of doing what was done—namely, translating the French designs into terms of standard American shop practice, a process which in numerous cases required weeks and even months of time on the part of whole staffs of experts working at high tension.

Nor do the French know the American quantity-production methods. The French artisan sees always the finished article, and he is given discretion in the final dimensions of parts and in the fitting and assembling of them. But the American mechanic sees only the part in which he is a specialist in machining; he works within strict tolerances and produces pieces which require little or no fitting in the assembling room. In the translating of French plans, therefore, it was necessary

FIGURE 7

Rates of Artillery Fire per Gun per Day in Recent Wars

War	*Army*	*Approximate rounds per gun per day*
1854-56, Crimean	British and French	[1] 5
1859, Italian	Austrian	.3
1861-65, Civil	Union	4
1866, Austro-Prussian	Austrian	2.2
	Prussian	.8
1870-71, Franco-Prussian	German	[2] 1.1
1904-05, Russo-Japanese	Russian	4
1912-13, Balkan	Bulgarian	7
World War		
September, 1914	French	[2] 8
Jan. 1-Oct. 1, 1918	Italian	[2] 8
Jan. 1-Nov. 11, 1918	United States	[2] 30
Jan. 1-Nov. 11, 1918	French	[2] 34
Jan. 1-Nov. 11, 1918	British	[2] 35

[1] Siege of Sebastopol. [2] Field-gun ammunition only.

The rates are based upon total expenditure and average number of guns in the hands of field armies for the period of the wars.

A large part of the heavy expenditure of artillery ammunition in the last as compared with other modern wars can be attributed to the increased rate of fire made possible by improved methods of supply in the field and by the rapid-fire guns now in use. In wars fought before the introduction of quick-firing field guns, four or five rounds a day was the greatest average rate. Even this was reached only in the siege of Sebastopol, where armies were stationary and supply by water was easy, and in the American Civil War, which was characterized by advanced tactical developments. The guns of the Allied armies in France fired throughout the year 1918 at a rate about seven times greater than these previous high rates.

to put into them what they had never had before: namely, rigid tolerances and exact measurements.

When an army of 100,000 men expands and becomes an army of 3,000,000, it becomes a job just 30 times bigger to feed the 3,000,000 than it was to feed the 100,000. A soldier

of a campaigning army eats no more than a soldier of a quiet military post. The same law is true approximately of clothing an army. But the army's consumption of ammunition in time of war is far out of proportion to its numerical expansion to meet the war emergency.

For instance, an army machine gun in time of peace might fire 6,000 rounds in practice during the year. This was the standard quantity of cartridges provided in peace. But for a single machine gun on the field in such a war as the recent one, it is necessary to provide 288,875 rounds of ammunition during its first year of operation, this figure including the initial stock and the reserve supply as well as the actual number of rounds fired. Thus the machine gun of war increases its appetite, so to speak, for ammunition 4,700 per cent in the first year of fighting.

For larger weapons, the increase in ammunition consumption is even more startling. Prior to 1917 the War Department allotted to each 3-inch field gun 125 rounds of ammunition a year for practice firing. Ammunition for the 75-millimeter guns (the equivalent of the 3-inch) was being produced in 1917-1918 to meet an estimated requirement of 22,750 rounds for each gun in a single year, or an increased consumption of ammunition in war over peace of 18,100 per cent.

Thus, when a peace army of 100,000 becomes a war army of 3,000,000 its ammunition consumption becomes not 30 times greater, but anywhere from 48 to 182 times 30 times greater—an increase far out of proportion to its increase in the consumption of food, clothing, or other standard supplies. Modern invention has made possible and modern practice has put into effect a greatly augmented use of ammunition. Figures 6, 7, and 8 show graphically how ammunition expenditure has increased in modern times.

Another circumstance that complicated the ordnance problem was the increasing tendency throughout the World War to use more and more the mechanical or machine methods of fighting as opposed to the older and simpler forms in which the human or animal factor entered to a greater extent.

FIGURE 8

Expenditure of Artillery Ammunition in Recent Wars

Past Wars Compared with One Month of World War

Year	*War*	*Army*	*Rounds expended during war*
1859	Italian	Austrian	15,326
1861-65	Civil	Union	5,000,000
1866	Austro-Prussian	Prussian	36,199
		Austrian	96,472
1870-71	Franco-Prussian	German	817,000
1904-05	Russo-Japanese	Russian	954,000
1912-13	Balkan	Bulgarian	700,000
1918	World	British and French	In one month.[1] 12,710,000

Expenditures for One Year, Civil and World Wars

1864[2]	Civil	Union	1,950,000
1918[3]	World	United States	8,100,000
1918[3]	World	British	71,445,000
1918[3]	World	French	81,070,000

[1] Average, year ended November 10, 1918. [2] Year ended June 30, 1864. [3] Year ended November 10, 1918.

The industrial effort necessary to maintain modern armies in action may be measured to a certain extent by their expenditure of artillery ammunition. European wars of the past hundred years were for the most part decided before peace-time reserves had been exhausted. The American Civil War, however, required for its decision an industrial mobilization at that time unprecedented, which, like the use in that war of intrenchments by field armies, was more truly indicative of the trend of modern warfare than were the conditions of the more recent European wars.

When the United States entered the war the regulations prescribed fifty machine guns as the equipment for an infantry division. When the armistice was signed the standard equipment of a division called for 260 heavy machine guns and 768 light automatic rifles. Of the heavy machine guns with a division, only 168 were supposed to be in active service, the remainder being in reserve or in use for anti-aircraft work. But the comparison of the two standards of equipment shows the tendency toward machine methods in the wholesale killing of modern warfare and indicates the fresh demands made upon the ordnance organization to procure this additional machinery of death. Moreover, when the fighting came to an end the A. E. F. was on the point of adding to its regimental and divisional equipment a further large number of automatic rifles.

The day of the horse was passing in the World War, so far as his connection with the mobile artillery was concerned, and the gasoline motor was taking his place, this tendency being accelerated particularly by America, the greatest nation of all in automotivity. Trucks and tractors to pull the guns, motor ammunition trucks displacing the old horse-drawn caissons and limbers, even self-propelling platforms for the larger field guns, with track-laying, or caterpillar, mounts supplying not only mobility for the gun but aiming facilities as well—these were the fresh developments. Some of these improvements were produced and put in the field; the others were under development at the signing of the armistice. The whole tendency toward motorization served to complicate ordnance production in this country, not only in the supply of the weapons and traction devices themselves, but also in the production of increased supplies of ammunition; for these improvements also tended to increase the rapidity with which bullets and shell were consumed.

The total cost of the ordnance alone required to equip the first 5,000,000 Americans called to arms was estimated to be between $12,000,000,000 and $13,000,000,000. This was equal to about half of all the money appropriated by Con-

Photo from Ordnance Department

AMERICAN-BUILT ORDNANCE AT ABERDEEN, MARYLAND

Photo from Willys-Overland, Inc.

INTERIOR OF A GREAT SHELL FACTORY

Photo from Ordnance Department

8-INCH HOWITZERS BUILT IN AMERICA

Photo from Ordnance Department

CAISSONS PARKED IN PROVING GROUND

gresses of the United States from the first Continental Congress down to our declaration of war against Germany—out of which appropriations had been paid the cost of every war we ever fought, including the Civil War, and the whole enormous expense of the Government in every official activity of a hundred and forty years. To equip with ordnance an army of this size in the period projected meant the expenditure of money at a rate which would build a Panama Canal complete every thirty days.

So much for some of the difficulties of the situation. In our favor we had the greatest industrial organization in the world, engineering skill to rank with any, a race of people traditionally versatile in applying the forces of machinery to the needs of mankind, inventive genius which could match its accomplishments with those of the rest of the world added together, a capacity for organization that proved to be astonishingly effective in such an effort as the nation made in 1917 and 1918, enormous stores of raw materials (the country being more nearly self-sufficient in this respect than any other nation of the globe), magnificent facilities of inland transportation, a vast body of skilled mechanics, and a selective-service law designed to take for the Army men nonessential to the nation's industrial efforts for war and to leave in the workshops the men whose skill could not be withdrawn without subtracting somewhat from the national store of industrial ability.

It only remains to sketch in swift outline something of the accomplishments of the American ordnance effort. In general it may be said that those projects of the ordnance program to which were assigned the shorter time limits were most successful. There never was a time when the production of smokeless powder and high explosives was not sufficient for our own requirements, with large quantities left over for both France and England.

America, in nineteen months of development, built over 2,500,000 shoulder rifles, a quantity greater than that produced by either England or France in the same period, although both those countries in April, 1917, at the time when

FIGURE 9

Production of Rifles, Machine Guns, and Ammunition: France and United States Compared with Great Britain

Average Monthly Rate, July, August, and September, 1918

Machine guns and machine rifles:		*Per cent of rate for Great Britain*
Great Britain	10,947	100
France	12,126	111
United States	27,270	249
Rifles:		
Great Britain	112,821	100
France	40,522	36
United States	233,562	207
Rifle and machine gun ammunition:		
Great Britain	259,769,000	100
France	139,845,000	54
United States	277,894,000	107

Total Production, April 6, 1917, to November 11, 1918

Machine guns and machine rifles:		*Per cent of rate for Great Britain*
Great Britain	181,404	100
France	229,238	126
United States	181,662	100
Rifles:		
Great Britain	1,971,764	100
France	1,416,056	72
United States	2,506,742	127
Rifle and machine gun ammunition:		
Great Britain	3,486,127,000	100
France	2,983,675,000	86
United States	2,879,148,000	83

we started, had their rifle production already in a high stage of development. (See Figure 9.) (The Franco-British production of rifles dropped in rate in 1918, because there was no longer need for original rifle equipment for new troops.)

In the nineteen months of war, American factories produced over 2,879,000,000 rounds of rifle and machine gun ammunition. This was somewhat less than the production in Great Britain during the same period and somewhat less than that of France; but America began the effort from a standing start, and in the latter part of the war was turning out ammunition at a monthly rate twice that of France and somewhat higher than that of Great Britain. (See Figure 9.)

Between April 6, 1917, and November 11, 1918, America produced as many machine guns and automatic rifles as Great Britain did in the same period, and 81 per cent of the number produced by France; and at the end of the effort America was building machine guns and machine rifles nearly three times as rapidly as Great Britain and more than twice as fast as France. (Figure 9.) When it is considered that a long time must elapse before machine gun factories can be equipped with the necessary machine tools and fixtures, the effort of America in this respect can be fairly appreciated.

Prior to November 11, 1918, America produced in the 75-millimeter size alone about 4,250,000 high-explosive shell, over 500,000 gas shell, and over 7,250,000 shrapnel. Of the high-explosive shell produced, 2,735,000 were shipped to France up to November 15, 1918. In all, 8,500,000 rounds of shell of this caliber were floated, nearly two-thirds of it shrapnel. American troops on the line expended a total of 6,250,000 rounds of 75-millimeter ammunition, largely high-explosive shell of French manufacture, drawn from the Franco-American ammunition pool. American high-explosive shell were tested in France by the French ordnance experts and approved for use by the French artillery just before the armistice.

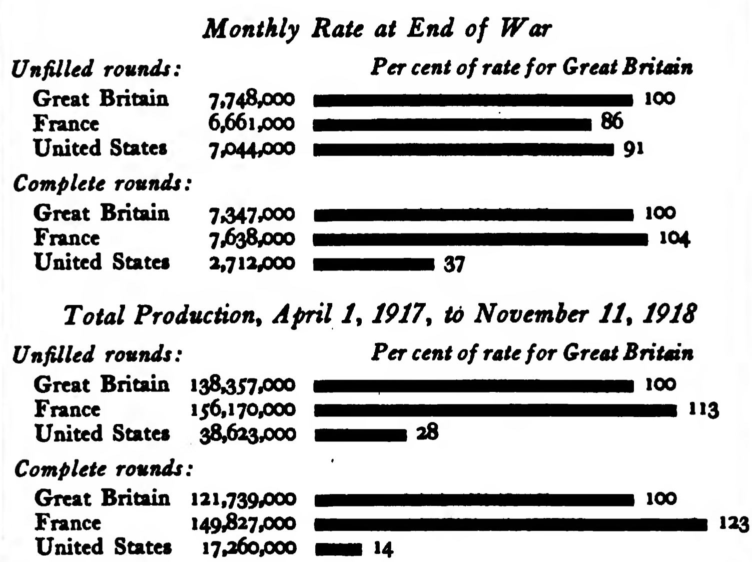
In artillery ammunition rounds of all calibers, America at the end of the war was turning out unfilled shell faster than the French and nearly as fast as the British; but, because of the shortage of adapters and boosters—a shortage rapidly being overcome at the end of the war—the rate of production of completed rounds was only about one-third that of either

Great Britain or France. In total production during her nineteen months of belligerency, America turned out more than one-quarter as many unfilled rounds as Great Britain did in the same time and about one-quarter as many as came from the French munition plants. In completed rounds alone did America lag far behind the records of the two principal Allies during 1917 and 1918. (Figure 10.)

FIGURE 10

Production of Artillery Ammunition: France and United States Compared with Great Britain

[Types for use in A. E. F.]

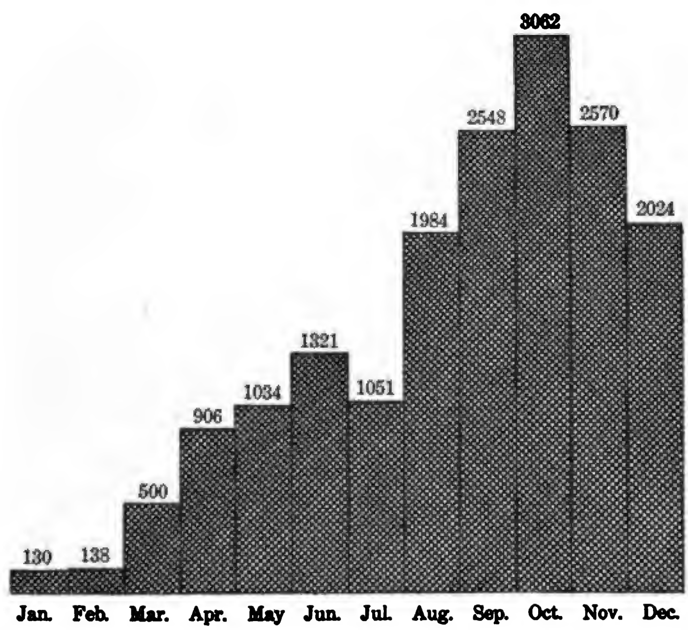


The production of completed rounds of artillery ammunition was gaining rapidly, beginning with the early summer of 1918, and in the month of October was approaching half the rate of manufacture in Great Britain or in France. Figure 11

shows graphically the rate at which the artillery ammunition deliveries were expanding.

FIGURE 11

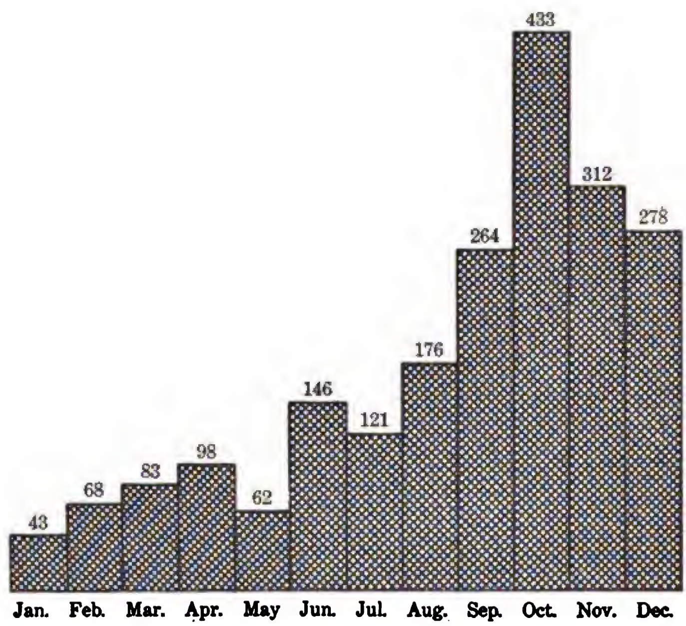
Complete Rounds of Artillery Ammunition Produced for the A. E. F. Each Month during 1918 (Figures in Thousands of Rounds)



In artillery proper, the war ended too soon for American industry to arrive on a great production basis. The production of heavy ordnance units is necessarily a long and arduous effort, even when plants are in existence and mechanical forces are trained in the work. America had in large part to build her ordnance industry from the ground up—buildings, machinery, and all—and after that to recruit and train the working forces. The national experience in artillery production in the World

FIGURE 12

Complete Units of Mobile Artillery Produced for the Army Each Month during 1918



War most like our own was that of Great Britain, which started from scratch, even as we did. It is interesting, then, to know how Great Britain expanded her artillery industry; and the testimony of the British Ministry of Munitions may throw a new light on our own efforts in this respect. In discussing artillery in the war, the British Ministry of Munitions issued a statement from which the following is an excerpt:

It is very difficult to say how long it was before the British army was thoroughly equipped with artillery and ammunition. The ultimate size of the army aimed at was continually increased during the first three years of the war, so that the ordnance requirements were continually increasing. It is probably true to say that the equipment of the army as

planned in the early summer of 1915 was completed by September, 1916. As a result, however, of the battle of Verdun and the early stages of the battle of the Somme, a great change was made in the standard of equipment *per* division of the army, followed by further increases in September, 1916. The army was not completely equipped on this new scale until spring, 1918.

Thus it took England three and a half years to equip her army completely with artillery and ammunition on the scale called for at the end of the war. On this basis America, when the armistice came, had two years before her to equal the record of Great Britain in this respect.

In the production of gun bodies ready for mounting, the attainments of American ordnance were more striking. At the end of the fighting America had passed the British rate of production and was approaching that of the French. In totals for the whole war period (April 6, 1917, to November 11, 1918) the American production of gun bodies could scarcely be compared with that of either the British or the French, for the reason that it required many months to build up the forging plants before production could go ahead.

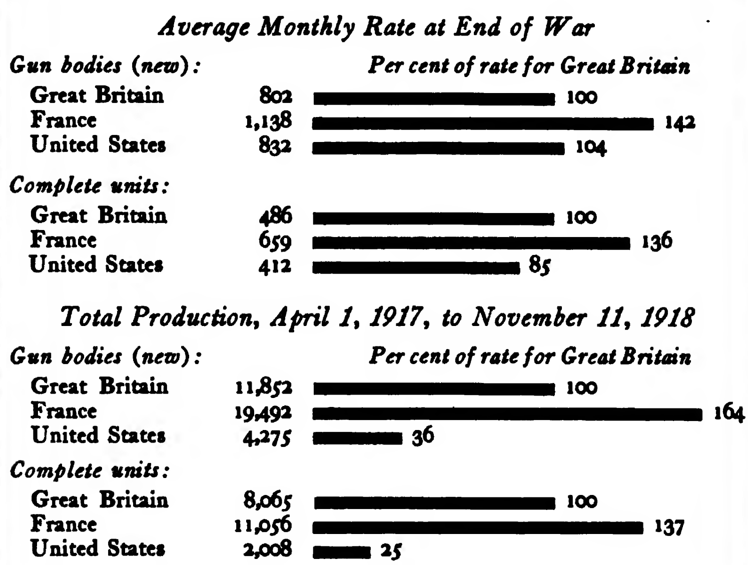
In completed artillery units the American rate of production at the end of the war was rapidly approaching that of the British and the French. In total production of complete units in the nineteen months of war, American ordnance turned out about one-quarter as many as came from the British ordnance plants and less than one-fifth as many as the French produced in the same period. Figure 13 represents visually America's comparative performances in the production of gun bodies and complete artillery units. (See also Figure 12.)

Stress has sometimes been laid upon the fact that the American Army was required to purchase considerable artillery and other supplies abroad, the latter including airplanes, motor trucks, food and clothing, and numerous other materials. Balanced against this fact is the consideration that every time we spent a dollar with the Allied governments for ordnance, we sold ordnance, or materials for conversion into munitions,

to the Allied governments to the value of five dollars. The Interallied Ordnance Agreement provided that certain munitions plants in the United States should continue to furnish supplies to the Allies, and that additional plants for the Allies should be built up and fostered by us. Thus, while we were purchasing artillery and ammunition from the Allies we were

FIGURE 13

Production of Artillery: France and United States Compared with Great Britain



shipping to them great quantities of raw materials, half-completed parts, and completely assembled units, and such wartime commodities as powder and explosives, forgings for cannon and other heavy devices, motors, and structural steel. The following table shows the ordnance balance sheet between America and the Allied governments:

Purchases and Sales from April 6, 1917, to November 11, 1918

Purchases: By Army Ordnance Department from Allied governments	**$ 450,234,256.85**
Sales:	
By Army Ordnance Department to Allied governments	**$ 200,616,402.00**
By United States manufacturers other than Army Ordnance Department to Allied governments	**2,094,787,984.00**
Total	**$2,295,404,386.00**

The credit for the ordnance record must go not merely to those men who wore the uniform and were part of the ordnance organization. Rather, it is due to American science, engineering, and industry, all of which combined their best talents to make the ordnance development worthy of America's greatness.

CHAPTER III

GUN PRODUCTION

THE sole use of a gun is to throw a projectile. The earliest projectile was a stone thrown by the hand and arm of man, in an attack upon either an enemy or a beast that was being hunted for food. Both of these uses of thrown projectiles persist to this day, and during all time, from prehistoric days until now, every man who has had a projectile to throw has been steadily seeking for a longer range and a heavier projectile.

The man who could throw the heaviest stone the longest distance was the most powerfully armed. In the Biblical battle between David and Goliath, the arm of David was strengthened and lengthened by a leather sling of simple construction. Much practice had given the young shepherd muscular strength and direction, and his longer arm and straighter aim gave him power to overcome his more heavily accoutered adversary.

Later, machines were developed after the fashion of a crossbow mounted upon a small wooden carriage, usually a hollowed trough open on top, upon which a heavy stone was laid. The thong of the crossbow was drawn by a powerful screw operated by man power, and the crossbow arrangement, when released, would throw a stone weighing many pounds quite a distance over the walls of a besieged city or from such walls into the camps and ranks of the besiegers. This again was an attempt by mechanical means to develop and lengthen the stroke of the arm and the weight of the projectile.

With the development of explosives, which began much earlier than many persons suppose, there came a still greater range and weight of projectile thrown, although the first guns were composed of mere staves of wood fitted together and hooped up like a long, slender barrel, and wound with wet

rawhide in many folds, which, when dried, exerted a compressive force upon the staves of the barrel exactly as do the steel hoops of barrels used in ordinary commercial life to-day.

This, the first gun, sufficed for a long while, until the age of iron came. And then the same principle of gun construction was followed, as is seen in that historic gun, the "Mons Meg," in the castle at Edinburgh. The barrel of that gun was made of square bars of iron placed lengthwise, around which similar bars of iron were wrapped hot to confine them in place and to give more resisting power than was possible with the wooden staves and the rawhide hooping.

Thus, all during the age of iron, gun development steadily progressed. Every military power was always striving, with the aid of its best engineers, designers, and manufacturers, to get a stronger gun, either with or without a heavier projectile; striving always for greater power. As a culminating development, we find in March, 1918, the now famous long-range gun of the Germans, which was at that time trained upon Paris, where it successfully delivered a shell punctually every twenty minutes for a good part of each day until the gun was worn out. This occurred after a comparatively small number of shots, probably not more than seventy-five in all. The rapid wearing out was due to the immense demands of the long range upon the material of the gun. The Germans in the shelling of Paris used three of these long-range weapons at a distance of about seventy miles, and 183 shell are known to have fallen in the city.

The Germans evidently calculated with great care and experience upon the factors leading up to this famous long-range gun, with its effective shooting distance of approximately seventy miles, a range which, in the opinion of our experts, it is now fairly easy for an experienced designer and manufacturer to equal and excel at will. In fact, one would hesitate to place a limit upon the range attainable by a gun that it is now possible to design and build. In this connection it is interesting to note that the great French ordnance works at Le Creusot produced in 1892 the first known and well-

authenticated long-range gun, which was constructed from the design of a 12-inch gun, but bored down to throw a 6-inch projectile. Instead of the usual eight miles expected from the flight of a 6-inch shell, this early Creusot long-range gun gave a range of approximately twenty-one miles with a 6-inch projectile, using a 12-inch gun's powder charge.

Closely connected with the development of the modern gun itself, and a necessary element of the gun's successful use, is the requirement that the weapon itself be easily transported from point to point, where its available range and capacity for throwing projectiles can be made of maximum use. This requires a gun carriage which contains within itself various functions, the primary one being that of establishing the gun in the position where it can be made most effective against the enemy. Then, too, the gun carriage must have stability in order to withstand and absorb the enormous recoil energies let loose by the firing of the gun. It is obvious that the force which propels the projectile forward is equal to the reacting force to the rear, and in order to care for, absorb, and distribute to the earth this reacting force to the rear, the carriage must have within itself some peculiar and important properties. To this end there is provided what is known as a "brake," which permits the gun, upon the moment of firing, to slide backward bodily within the controlling apparatus mounted upon a fixed carriage.

The sliding of the whole gun to the rear by means of the mechanism of the brake is controlled, as to speed and time, by springs, by compressed air, and by compressed oil, either all together or in combinations of two or three of these agencies; so that the whole recoil energy is absorbed and the rearward action of the gun brought to rest in a fraction of a second and in a few inches of travel. The strains are distributed from the recoil mechanism to the fixed portion of the carriage, necessarily anchored to the ground by means of spades, which the recoil force of each shot sets more firmly into the ground, so that the whole apparatus is thus steadily held in place for successive shots.

In mobile artillery, again, rapid firing is a prime essential. The 75-millimeter gun of modern manufacture is capable of being fired at a rate in excess of twenty shots a minute—that is, a shot every three seconds. Seldom, however, is a gun served as rapidly as this. The more usual rate of fire is six shots a minute, or one about each ten seconds; and this rate of fire can be maintained in the 75-millimeter gun with great accuracy over a comparatively long period.

The larger guns are served at proportionately slower rates, until, as the calibers progress to the 14-inch rifles, which have been set up on railway mounts as well as on fixed emplacements for seacoast defense, the rate of fire is reduced to one shot in three minutes for railway mounts, and to one shot a minute for seacoast mounts, although upon occasions a more rapid rate of fire can be reached.

Under rapid-fire conditions, the gun becomes extremely hot, owing to the heat generated by the combustion of the powder within the gun at pressures as high as 35,000 pounds or more to the square inch, pressures generated at the moment of fire. This heat is communicated through the walls of the gun and taken off by the cooling properties of the air. Nevertheless, the wall of the gun becomes so hot that it would scorch or burn a hand laid upon it. Rapid fire and the consequent heating of the gun lessen the effective life of the weapon, because the hot powder gases react more rapidly on hot metal than on cold; hence a gun will last many rounds longer if fired at a slow rate.

It may be helpful to keep in mind throughout that, as was stated at the very beginning of this chapter, the sole purpose of a gun is to fire a projectile. All other operations connected with the life of a gun—its manufacture, its transportation to the place where it is to be used, its aiming, its loading, and all its functions and operations—are bound up in the single purpose of actually firing the shot.

Consider now for a moment the life of, let us say, one of the 14-inch guns. In the great steel mills it requires hundreds, perhaps thousands, of workmen to constitute the force neces-

sary to handle the enormous masses of steel through the various processes which finally result in the finished gun. From the first operation in the steel mill it requires perhaps as long as ten months to produce the gun, ready for the first test. During the ten months of manufacture of one of these 14-inch rifles there has been expended for the gun and its carriage approximately $200,000. (Of course, although it requires ten months to make a final delivery of one gun after the first process is commenced, it should be remembered that yet other guns are following in series, and that in a well-equipped ordnance factory two and perhaps three guns a month of this kind can be turned out continuously, if required.) Remembering that it requires ten months to produce one such 14-inch rifle and that its whole purpose is to fire a shot, consider now the time required to fire this shot. As the primer is fired and the powder charge ignited, the projectile begins to move forward in the bore of the gun at an increasingly rapid rate, so that, by the time it emerges from the muzzle and starts on its errand of death and destruction, it has taken from a thirtieth to a fiftieth of a second in time, depending upon certain conditions. Assuming that a fiftieth of a second has been taken up and that the life of a large high-pressure gun at a normal rate of firing is 150 shots, it is obvious that in the actual firing of these 150 shots only three seconds of time are consumed. Therefore, the active life of the gun, which it has taken ten months to build, is but three seconds long in terms of the actual performance of its function of throwing a shot.

However, after the gun has lived its life of 150 shots it is a comparatively simple and inexpensive matter to bore out the worn-out liner and insert a new liner, thus refitting the gun for service, with an expenditure of time and money much less than would be required in the preparation of a new gun.

As the size of the powder charge decreases, a progressively longer life of the walls of the bore of a gun is attained, so that we have had the experience of a 75-millimeter gun firing 12,000 rounds without serious effect upon the accuracy of fire. Large-caliber guns, such as 12-inch howitzers, with the re-

Photo from Ordnance Department

CHARGING FLOOR OF AN OPEN HEARTH FURNACE BUILDING

Photo from Midvale Steel Company

BIG GUNS READY TO BE SHIPPED

Photo from Ordnance Department

LADLE RECEIVING MOLTEN STEEL

Photo from Ordnance Department

CASTING GUN INGOT. "A" INDICATES COMPLETED INGOT WITH SINKHEAD ON TOP

duced powder charge required for the lower muzzle velocities employed in howitzer attack, have retained their accuracy of fire after 10,000 rounds.

Because in action guns are served with ammunition, aimed, fired, and cared for by a crew of men carefully trained to every motion involved in the successful use of the gun, it is most essential that the design and its calculation and the material and its manufacture shall all be such as will foster the morale of the crew that serves the gun. Each man must be confident to the very last bit of fiber in his make-up that his gun is the best gun in the world, that it will behave properly, that it will protect him and his fellow soldiers who are caring for the welfare of their country, that it will respond accurately and well to every demand made upon it, that it will not yield or burst, that it will not shoot wild—in fine, that it will in every respect give the result required in its operation. It has been known for generations that to this end the requirements of manufacture of ordnance material, particularly for the body of the gun, are of the very highest order and call for the finest attainable quality in material, workmanship, and design. It is well known that the steel employed in the manufacture of guns must be of the highest quality and of the finest grade for its purpose. It requires the most expert knowledge of the manufacture of steel to obtain this grade and quality. Until recently this knowledge in America was confined to the ordnance officers of the Army and of the Navy and to a comparatively small number of manufacturers,—not more than four in all,—and only two of these manufacturers had provided the necessary equipment and appliances for the manufacture of complete guns.

Until 1914 the number of guns whose manufacture was provided for in this country, as well as in the countries of Europe, excepting Germany, was small. The sum total of guns purchased by the United States from the two factories mentioned did not exceed an average of fifty-five guns a year in calibers of from 3-inch to 14-inch; and the stock of guns which had been provided for us by this low rate of increase of manu-

facture was a pitifully small one with which to enter a war of the magnitude of the one through which this country has just passed. The two factories in question, not having been encouraged by large purchases of ordnance material, as similar industries were in Germany, were not capable of volume production when we entered the war. But at the same time the gun bodies produced by these concerns at least equaled in quality those built in any other country on earth. The big-gun-making art was, then, in existence in this country and was maintained as to quality; but it was most insufficient as to the quantity of the production available.

When the United States faced the war in April, 1917, arrangements were entered into to obtain in the shortest space of time an adequate supply of finished artillery of all calibers required by our troops. Many thousands of forgings for guns, and finished guns, too, had been ordered by the Allies from the few gunmakers in this country; and these makers were, when we entered the conflict, fully occupied for at least a year ahead with orders from the French and English ordnance departments. All this production was immediately useful and available for the combined armies of the Allies, and therefore it was allowed to go forward, the forgings preventing a gap in the output of the finished articles from the British and French arsenals which were then using the semi-finished guns made in the old factories in existence in this country in April, 1917.

Some idea of the volume of this production in this country will be gained from the following table of material supplied to the Allies between April, 1917, and the signing of the armistice, November 11, 1918:

Guns of calibers from 3-inch to 9.5-inch furnished to the Allies		1,102
Additional gun forgings furnished to the Allies	tubes	14,623
Shell and shell forgings furnished to the Allies in this period	pieces	5,018,451

In supplying all this material from our regular sources of

manufacture in this country to the finishing arsenals of the Allies, we were but maintaining our position as a part of the general source of supply. The plan of the French and British ordnance engineers at the outbreak of the war in 1914 was to build their factories as quickly and as extensively as could be done. By the time the United States entered the war, all these factories were in operation and clamoring for raw material at a rate far in excess of that which could be attained by the home steel makers in Great Britain and France. Consequently their incursions into the semi-finished ordnance material supplies in the United States were necessary. In sending these large quantities of our materials abroad, when we needed them ourselves, we were distinctly adding to the rate and quantity of the supply of finished ordnance for the use of our own Army in the field, as well as being at the same time of inestimable help to the Allies; for the French and British had agreed to supply our first armies with finished fighting weapons while we were giving them the raw materials which they so badly needed.

The total of four gunmakers in America was meanwhile being expanded into a total of nineteen. All these nineteen factories, by the month of October, 1918, were in practically full operation. Many of them were producing big guns at a faster rate than that for which the plants had been designed. In the month of October, 1918, with three of the nineteen factories yet to have their machine-tool equipment completed, there were produced 2,059 sets of gun forgings between the 3-inch and 240-millimeter calibers, which is production at the rate of upward of 24,000 guns a year. This figure, of course, does not indicate anything of the gun-finishing capacity of the country; but the expansion may be contrasted to the fact that our supply of finished guns prior to 1917 amounted to only fifty-five weapons a year.

Our chain of gun factories—the factories which were accomplishing this remarkable production—was forged of the following links:

One at the Watertown Arsenal, Watertown, Massachu-

Production of Finished Cannon, 75 Millimeters to 240 Millimeters in Size, at the Various Machining and Assembling Plants[1]

	1917 to Dec.	1918 Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	1919	Total War Production
75 mm.	5	59	51	35	74	127	169	142	204	199	312	223	260	906	2,766
3-inch anti-aircraft	3	21	25	10	2	3	8	12	11	20	50	34	32	74	305
4.7-inch gun							6	8	15	29	71	50	50	188	417
155-mm. howitzer			4	9	16	49	55	109	248	206	350	231	206	306	1,789
155-mm. gun								2		14	51	22	48	355	492
8-inch howitzer	1	6	7	20	38	8			28	22	33	14	14	54	245
240-mm. howitzer									1			1		190	192
Total	9	86	87	74	130	187	238	273	507	490	867	575	610	2,073	6,206

Monthly Production of Cannon Forgings

	1917 to Dec.	1918 Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	1919	Total War Production
75 mm.	124	89	105	92	157	344	263	1,000	776	898	1,456	399	237	37	5,977
3-inch anti-aircraft	70	9	20	14	8	21	59	13	31	46	235	49	18	3	596
4.7-inch gun			9	6	12	28		70	109	74	22	45	59	8	442
155-mm. howitzer	2	20	20	62	47	166	159	154	273	260	165	277	107	261	1,973
155-mm. gun					1	16	7	45	22	75	136	54	60	467	883
8-inch howitzer	37	21	9	5	23	29	20	22	19	11	11	24	10	5	246
240-mm. howitzer					1	3	3	15	13	18	34	46	36	241	410
Total	233	139	163	179	249	607	511	1,319	1,243	1,382	2,059	894	527	1,022	10,527

[1] Carriages, recuperators, and sights had to be added to these cannon to make them complete units ready for service.

setts, near Boston, for the manufacture of rough-machined gun forgings of the larger mobile calibers. This factory was entirely built and equipped on government land with government money, and could produce rough-machined gun forgings of the highest quality at the rate of two sets a day for the 155-millimeter G. P. F. rifles, and one set a day for the 240-millimeter howitzers.

At Watervliet Arsenal, Watervliet, New York, large extensions were made to the existing plant, which had always been the Army's prime reliance for the finishing and assembly of guns of all calibers, including the very largest. This plant was extended to manufacture complete four of the 240-millimeter howitzers each day, and two a day of the 155-millimeter G. P. F. guns.

At Bridgeport, Connecticut, there was constructed by the Bullard Engineering Works a complete new factory, capable of turning out for the United States four 155-millimeter G. P. F. guns a day.

At Philadelphia, the Tacony Ordnance Corporation, as agents for the Government, erected complete a new factory, officered and manned by experts well trained and experienced in the difficult art of the manufacture of steel and gun forgings. On October 11, 1917, the grounds for this great undertaking had been merely staked out for the outline of the buildings. Seven months later, on May 15, 1918, the entire group of buildings, a complete steel works for every process from making the steel to the final completion of 155-millimeter gun forgings, was finished at a cost of about $3,000,000. This difficult and rapid building operation was carried through successfully during the extraordinarily severe winter of 1917-1918. On June 29, 1918, the first carload of gun forgings was accepted and shipped from this plant; so that we here review the marvelous exploit of building a complete steel works from the bare ground forward to the shipment of its first forgings in a total elapsed time of only eight and one-half months.

At another plant, the works of the Midvale Steel Company, in Philadelphia, large extensions were made to enable some

of the larger guns to be produced, to be finished later at the Watervliet Arsenal.

At the Bethlehem Steel Company's plant, Bethlehem, Pennsylvania, as early as May, 1917, orders were placed and appropriations allotted for expansions to this enterprise, to enable a rapid output of a larger number of gun forgings and finished guns.

Large extensions were made at the works of the Standard Steel Works Company, Burnham, Pennsylvania, to increase their existing forging and heat-treating facilities. At this plant two sets of 155-millimeter howitzer forgings and one set of 155-millimeter gun forgings were produced each day.

At Pittsburg, Pennsylvania, the plants of the Heppenstall Forge & Knife Company and the Edgewater Steel Company were extended so as to provide for the daily production, at the first plant, of forgings for one 3-inch anti-aircraft gun and one 4.7-inch gun, and, at the second plant, of forgings for one 155-millimeter G. P. F. gun and one 240-millimeter howitzer a day.

At Columbus, Ohio, the Buckeye Steel & Castings Company, in combination with the works of the Symington-Anderson Company, at Rochester, New York, had their facilities extended to provide for the manufacture each day of six sets of forgings for 75-millimeter guns.

At the Symington-Anderson Company in Rochester, New York, there was provided a finishing plant for the 75-millimeter gun with a capacity of fifteen finished guns a day.

At Erie, Pennsylvania, one of the most remarkable achievements in rapid construction and successful mechanical operation was performed by the erection of a plant commenced in July, 1917, out of which the first production was shipped to the Aberdeen Proving Ground in February, 1918. The American Brake Shoe & Foundry Company built and operated this plant as agents for the Ordnance Department, and much credit is due them for their energy and organizing capacity. It is doubtful if history records any similar enterprise in which guns were turned out in a plant seven months from the date of

beginning the erection of the factory. This plant was laid out to manufacture ten of the 155-millimeter Schneider-type howitzers a day, and before the signing of the armistice it had more than fulfilled every expectation by regularly turning out up to fifteen howitzers a day, or ninety a week.

At Detroit, Michigan, the Chalkis Manufacturing Company adapted an existing plant and erected additional facilities for the manufacture of three 3-inch anti-aircraft guns each day.

At Madison, Wisconsin, the Northwestern Ordnance Company erected for the United States an entirely new factory, beautifully equipped for the manufacture of four guns a day of the 4.7-inch model.

At Milwaukee, Wisconsin, the Wisconsin Gun Company put up for the Government an entirely new works capable of finishing six 75-millimeter guns each day. The plants at both Milwaukee and Madison acquitted themselves well and gave us guns of the highest quality.

At Chicago, the Illinois Steel Company expanded existing facilities to produce more of the necessary electric-furnace steel, which was forged into guns at several works producing gun forgings, both for the Army and Navy.

At Indiana Harbor, Indiana, the works of the Standard Forgings Company, whose sole business had been the volume production of forgings with steam hammers and hydraulic presses, were expanded to the enormous extent of producing each day ten sets of gun forgings for the 155-millimeter howitzer and twenty-five sets a day for the 75-millimeter gun. This was a triumph of organizing ability, and this factory was one of our main reliances for these guns.

At Gary, Indiana, the American Bridge Company created what is perhaps the finest gun-forging plant in the world, comprising four presses from 1,000 tons' to 3,000 tons' forging capacity and all the other necessary apparatus for the production each day of two sets of 155-millimeter G. P. F. gun forgings and the equivalent of one and one-half sets a day of 240-millimeter howitzer forgings.

At Baltimore, Maryland, the plant of the Hess Steel Corporation was enlarged from its peace-time capacity until it could produce at three times its normal rate the special steels required for gun manufacture.

It will become evident that the collection of the machinery, buildings, and equipment necessary to produce these guns, in the short space of time required and at the rate of production stipulated, was an enormous task. It required the production of vast quantities of raw materials and the congregating in one place of large numbers of men capable of undertaking the exceedingly intricate mechanical processes of manufacture. The success of this plan and of its execution is due largely to the loyalty of the manufacturers who came forward early in 1917 and agreed, at the request of the Ordnance Department, to turn over their plants, lock, stock, and barrel, to the requirements of the Department; agreed also to undertake the manufacture of products totally unfamiliar to them; agreed likewise to lend all their organizing ability and great material resources to the success of the plants which the United States found it necessary to build in the creation of a new art, in new locations, and to an extent theretofore undreamed of.

Steel, of course, and steel in some of its finest forms, is the basis of gun manufacture. The word "steel," in connection with producing guns, means much more than is ordinarily carried by the word in its everyday and commonly accepted use. Only steel of the highest quality is suitable for gun manufacture, as we indicated previously in directing attention to the complete reliance which the operating crews must place on their guns and to the severity of the uses to which the big guns are put. Let us take a hasty trip through a big gun plant, watching the processes through which one of our hardy and efficient big guns is finally evolved from the raw material.

Entering an open-hearth furnace building at one of our big gun plants, we find two large furnaces in which the raw materials are charged. Each of these furnaces is 75 feet long and

15 feet wide. In each of them, in a shallow bath or pool, lies the molten steel. The pool is about 33 feet long by 12 feet wide and approximately 2½ feet deep. This pool, or "bath," as it is termed, weighs approximately sixty tons. It is composed of pig iron and well-selected scrap steel, the residue from previous operations.

At all times during the operation of melting these raw materials in the bath, the furnace is kept at such a high temperature that the eye can not look within at the molten mass without being protected with blue glass or smoked glass, exactly as when looking at the noonday sun. The naked eye can see nothing in the atmosphere of the bath in which the steel is being melted and refined, because the temperature is so exceedingly high that it gives a light as white as that of the sun.

After twelve or fifteen hours of refining treatment in this furnace, the metal is tested, analyzed in the chemical laboratory, and, if found to be refined to the proper degree, is allowed to flow out of the furnace on the opposite side from that through which it entered. Flowing out of the furnace, the entire charge of sixty tons finds its way into a huge ladle which is suspended from a traveling crane capable of safely carrying so great a weight.

The ladle is then transferred by the crane to a heavy cast-iron mold, built so as to contain as much of the sixty tons of molten metal as is required for the particular gun forging under manufacture. The mold which we have before us now on our imaginary trip through the gun plant will provide from the molten metal an "ingot" 40 inches in diameter and 100 inches high. On top of this ingot will be a so-called "sink-head," lined with brick. This sinkhead is that portion of the molten metal which has been allowed to cool more slowly in the brick lining than the ingot does in the cast-iron mold proper. The ingot, with the sinkhead, will weigh approximately 60,000 pounds. The sinkhead is cast in order to ensure greater solidity to the portion of the ingot which is used for the gun forging. Only that part of the ingot below the sink-

head enters the forging. The sinkhead itself is cut off, while hot, under the press in a subsequent operation, and afterwards remelted.

Next, the ingot is placed under a 2,000-ton forging press, a machine which can take ingots up to 45 inches in diameter. There, after coming from the mold in an octagonal form, it is forged into a square shape. Previously to its being put under this press, however, a careful chemical analysis has been made of the ingot to ascertain whether it be satisfactory for gun purposes; and also before being put under the press, the whole ingot is heated in the charge chamber with either a gas or an oil flame.

After the ingot forging has been, by further operations in the press, reduced from squareness to a cylindrical shape, it is allowed to cool; then it is taken to the machine shop, where it is turned and the hole through which the projectile ultimately will pass is bored into it. This hole is somewhat smaller than the diameter of the projectile, because in the finishing operation, when the gun is assembled finally and put together, the hole must be within one one-thousandth of an inch of the diameter required, which is all the tolerance that is allowed from the accuracy to which the projectiles are brought. Otherwise the accuracy of the gun in firing would be injured and the reliability of its aim would not be satisfactory.

During all these operations with the ingot, the steel is largely in the soft condition in which it left the forging press. As is well known, steel is capable of taking many degrees of "temper." Temper is an old term, no longer quite descriptive of the condition desired or obtained, but it is sufficiently expressive of the condition desired to serve our purposes here. This condition is one of a certain degree of hardness—greater than that of ordinary steel—combined with the greatest obtainable degree of toughness. This combination of hardness and toughness, produced to the proper degree, resists the explosive power of the powder and also causes the wear on the gun in firing to be diminished and made as slight as possible.

To effect this combination of hardness and toughness, it is

Photo from Midvale Steel Company

HYDRAULIC FORGING PRESS
IN GUN PLANT

Photo from Ordnance Department

155-MILLIMETER GUN TUBES READY
FOR HEATING

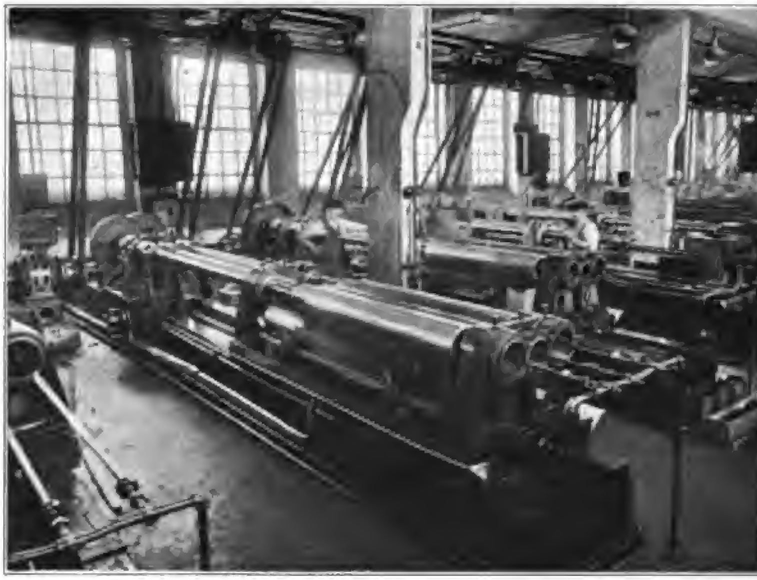


Photo from Otis Elevator Company

BORING 240-MILLIMETER RECUPERATORS

Photo from Morgan Engineering Company

SHOP IN WAR ORDNANCE PLANT

necessary to take the bored and turned tubes of the guns and suspend them by means of a specially made apparatus in a furnace where they are heated for a period of perhaps eight hours to a temperature of approximately 1,500 degrees F., or to a bright yellow color, uniform in every part of the piece.

After being subjected to this treatment for the time mentioned, the tube is then conducted by means of a traveling crane apparatus to a tank of warm water into which it is dipped and the heat rapidly taken from it down to a point practically of atmospheric temperature. This "quench," as it is called, produces the degree of hardness called for by the ordnance officers' design; but the piece has not yet reached the required degree of toughness. This toughness is now imparted to the hard piece by heating it once more in another furnace to a temperature of approximately 1,100 degrees F., or to a warm rosy red, for a period of perhaps fourteen hours. From this temperature the piece is allowed to cool naturally and slowly to the atmospheric temperature.

The ordnance inspectors at this point determine whether the piece has the required properties in a sufficient degree, by cutting from the tube a piece five inches long and half an inch in diameter. The ends of this piece are threaded suitably for gripping in a machine. The piece is then pulled until the half-inch stem breaks. The machine registers the amount of force required to break this piece, and this gives the ordnance engineer his test as to the degree of hardness and toughness to which the piece has been brought by the heat-treatment processes just described.

A satisfactory physical condition having been determined by pulling and breaking the test pieces as described, the whole forging is sent to the finishing shop, where it is machined to a mirror polish on all its surfaces. The diameters are accurately measured and the forgings assembled into the shape of a finished gun.

In this process there is required a different kind of care and accuracy. Until this time the care has been to provide a metal of proper consistency and quality. From this point forward

the manufacture of a gun requires the machining and fitting of this metal into a shape and form so accurate that the full strength of the gun and the best accuracy of fire can be realized.

First, a few lines to explain how and why hoops are placed upon the gun tubing, and how the various hoops are shrunk from the outside diameter of the gun. Cannon are made of concentric cylinders shrunk one upon another. The objects of this method of construction are two. The distinctly practical object is the attainment throughout the wall of each cylinder of the soundness and uniformity of metal which are more certainly to be had in thin pieces than in thick ones; the other object is more closely connected with the theory of gun construction.

When a hollow cylinder is subjected to an interior pressure, the walls of the cylinder are not uniformly strained throughout their thickness, but the layer at the bore is much more severely strained than that at the outside. This law can readily be tested if we consider a cylinder of rubber with, for example, a bore of one inch and an exterior diameter of three inches—about the proportions of many guns. If we put an interior air pressure in the cylinder until we expand the bore to two inches, the exterior diameter will not thereby be increased one inch. But supposing that it were increased as much as the bore,—that is, one inch,—we should have the diameter, and therefore the circumference, of the bore increased 100 per cent, and the circumference of the exterior increased 33⅓ per cent. That is, the layer at the bore would be strained three times as much as that at the exterior, and the interior layer would begin to tear before that at the exterior would reach anything like its limit of strength. The whole wall of the cylinder would therefore not be contributing its full strength toward resisting the interior pressure, and there would be a waste of material as well as a loss of strength.

Let us now consider, instead of our simple cylinder, a built-up cylinder composed of two concentric ones, the inner one of a bore originally a little greater than one inch, and the outer one of exterior diameter a little less than three inches, origi-

nally; so that, when the outer one is pressed over the inner one (its inner diameter being originally too small for it to go over the inner one without stretching), the bore of the inner one is brought to one inch, and the exterior of the outer one to three inches. We now have a cylinder of the same dimensions as our simple one, but in a different state, the layers of the inner one being compressed and those of the outer one extended.

If now we begin to put air pressure on the bore, we can put on a certain amount before we wipe out the compression of the inner layer and bring it to a neutral state; and thereafter we can go on putting on more pressure until we stretch the inner layer 100 per cent beyond the neutral state, as before; which would take just as much additional pressure as the total pressure which we employed with our simple cylinder. We have therefore gained all that pressure which is necessary to bring the inner layer of our built-up cylinder from its state of compression to the neutral state. If we have so proportioned the diameter of junction of our inner and outer cylinders and so gauged the amount of stretching required to get the outer one over the inner one that we have not in the process caused any of the layers of the outer one to be overstrained, the gain has been a real one, attained by causing the layers of the outer cylinder to make a better contribution of strength toward resisting the interior pressure. This is the theory of the built-up gun.

The number of cylinders employed generally increases, up to a certain limit, with the size of the gun, practical considerations governing; and the "shrinkage," or amount by which the inner diameter of the outer cylinder is less than the outer diameter of the one which it is to be shrunk over, is a matter of nice calculation. Roughly speaking, it is about one and one-half one-thousandths of an inch for each inch of diameter, varying with the position of the cylinder in the gun; and the accurate attainment of such precise dimensions throughout the length of the cylinder of a large gun, is a delicate matter of the gunmaker's art and the machinist's skill.

The method of assembly is to have the cold tube set upright and prepared for a circulation of water within the bore of the tube to keep it cool. Then the hoop, whose inside diameter is smaller than the outside diameter of the tube on which it is to be shrunk, is measured and carefully heated to a temperature of approximately 450 degrees F., or just about the temperature of a good oven for baking or roasting. This mild temperature so expands the material in the hoop that the difference of diameter is overcome and the hot hoop is expanded to a larger inside diameter than the outside of the cold tube on which the hoop is to be placed. Next, the hot expanded hoop is placed in position around the breech end of the tube, and slowly and carefully cooled, so that in contracting from the high temperature to the low ordinary temperature, the hoop shrinks toward its original diameter and thus exerts an enclosing pressure or compressive strain upon the breech end of the tube. Now, when the gun is fired the tube tends to expand under the pressure, and this expansion is resisted, first by the compressive force exerted by the shrunken hoop and later by the hoop itself; so that the built-up construction is stronger and better able to resist the explosive charge of the burning powder than if the gun were made in one piece and were of the same thickness of metal.

This brief explanation will show why so many pieces are provided for the manufacture of the finished gun and why so large a number of machine tools and machining operations is necessary in order to carry forward the manufacture of the finished article.*

Both our 4.7-inch gun, Model 1906, with which our troops have been equipped for a long time and which throws a projectile weighing forty-five pounds a distance of about six miles, and the French 75-millimeter (2.95-inch) gun, successfully used by the French since 1897, were designed to be drawn by horses; and the guns are best used when drawn by teams of six or eight horses. As the horse has a sustained pulling power of

* Sometimes one of the outer cylinders is replaced by layers of wire, wound under tension; sometimes more than one are so replaced.

only 650 pounds, it is obvious that the weight to be drawn by the team of six horses must not be more than 3,900 pounds. There is, therefore, every incentive for making mobile artillery of this kind as light as possible, consistently with the strength required for the work to be done. Thus the pulling power of the horse, coupled with his speed, has been the limiting factor in the design and weight of mobile field artillery. As one of our foremost United States ordnance engineers once said: "The limited power of the horse is what has governed the weight of our artillery. . . . If Divine Providence had given the horse the speed of the deer and the power of the elephant, we might have had a far wider and more effective range for our mobile artillery."

One of the answers of the United States ordnance engineers to this problem, as developed in the recent war, has been the production of a tractor to replace the horse; a tractor which has the speed of the deer and the power of the elephant. The most powerful tractors are mounted on track-laying devices and are colloquially known as caterpillars. One of these powerful caterpillars on which is mounted an 8-inch howitzer, with a range of six miles,—the tractor is manned and operated by only two men, and it can go uphill and downhill, over broken brushwood, trees, and the like,—was given a severe test at the Aberdeen Proving Ground. It was sent through a dense wood in which it bumped squarely into a live locust tree seventeen inches in diameter at the base. This tree, almost the tallest in the wood, was prostrated by the attack of the tractor, which rode over it and then emerged from the wood, took up its position, and fired its shot in almost as short a time as it takes to tell of the feat. Truly the power of the elephant and the speed of the deer have been brought to the aid of the ordnance engineer for any future warlike operations.

The number of workmen employed in gun production at once in this country totaled 21,000, and fully as many more are estimated to have been employed in the manufacture of gun carriages and fire-control instruments. These men became

so skilled in their work that the difficult art of gunmaking has become firmly established in this country. The United States may now and at any time in the near future rely on this trained body of artisans for the finest kind of gun-metal manufacture.

CHAPTER IV

MOBILE FIELD ARTILLERY

THE chance observer might assume that, once the Ordnance Department had succeeded in putting in production the cannon of various sizes described in the preceding chapter, the battle of providing artillery was as good as won. But no: even after the ponderous tubes had come finished from the elaborate processes of the steel mills, the task of the ordnance officers had only begun. Each gun had to be rendered mobile in the field and it had to be equipped with a mechanism to take up the retrograde shock of firing (the "kick") and to prevent the weapon from leaping out of aim at each discharge. Mobility is given to a gun by the carriage on which it rides. The device which absorbs the recoil and restores the gun to position is called the recuperator (in the hydropneumatic French design), or the recoil mechanism. Carriage and recuperator, or recoil mechanism, are together known as the mount.

The forging, boring, reinforcing, machining, and finishing of the gun body are not half the battle of manufacturing a modern military weapon; they are scarcely one-third of it. No ordnance officer of 1917-1918 will ever forget the heartbreaking experiences of manufacturing the mounts, a work which went along simultaneously with the production of the cannon themselves. The manufacture of carriages often presented engineering and production problems of the most baffling sort. As to the recuperators, a short analysis of the part they play in the operation of a gun will indicate something of the scope of the project to build them in quantities.

The old schoolbook axiom that action and reaction are equal and opposite has a peculiar emphasis when applied to the

firing of a modern piece of high-power artillery. The force exerted to throw a heavy projectile seven miles or more from the muzzle of a gun is exerted equally toward the breech of the weapon in its recoil. Some of these forces, handled so safely and easily by mechanical means, are almost beyond the mind's grasp.

Not long ago a touring car weighing two tons traveled at the rate of 120 miles an hour along a Florida beach. Conceive of such a car going 337 miles an hour, which is much faster than any man ever traveled; then conceive of a mechanism which would stop this car, going nearly six miles a minute—stop it in forty-five inches of space and half a second of time, without the slightest injury to the automobile. That is precisely the equivalent of the feat performed by the recuperator of a 240-millimeter howitzer after a shot. Or, conceive of a 150,000-pound locomotive traveling at 53.3 miles an hour. The action of the 240-millimeter recuperator after a shot is equivalent to stopping that locomotive in less than four feet in half a second without damage.

The forging for the 155-millimeter howitzer's recuperator is a block of steel weighing nearly two tons—in exact figures, 3,875 pounds. This must be bored and machined out until it weighs, with the accessory parts of the complete recuperator placed on the scales with it, only 870 pounds. It is scarcely fair to a modern hydropneumatic recuperator to say that it must be finished with the precision of a watch. It must be finished with a mechanical nicety comparable only to the finish of such a delicate instrument as a navigator's sextant or the mechanism which adjusts the Lick telescope to the movement of the earth. No heavy articles ever before turned out in American workshops required in their finish the degree of microscopic perfection which the recuperators exacted.

We adopted from the French, the greatest of all artillery builders, four recuperators—one for the 75-millimeter gun, one for the 155-millimeter gun, another for the 155-millimeter howitzer, and the fourth for the 240-millimeter howitzer. These mechanisms had never been built before outside France.

Indeed, one could find pessimists ready to say that none but French mechanics could build them at all, and that our attempt to duplicate them could end only in failure. Yet American mechanical genius "licked" every one of these problems, as the men in the greasy overalls say, and did it in little more than a year after the plans came to the workshops. There was not one of these beautiful mechanisms, in France the product of patient handiwork on the part of metal craftsmen of deep and inherited skill, that did not eventually become in American workshops a practical proposition of quantity production.

The problem of building French recuperators in the United States may be regarded as the crux of the whole American ordnance undertaking in the war against Germany, the index of its success. It presented the most formidable challenge of all to American industrial skill. Men whose opinion had to be considered were convinced that it was impracticable to attempt to produce French recuperators here. Although the superiority of these recoil devices in their respective classes was universally conceded, Germany had never been able to make them, and England, with the coöperation of the French ordnance engineers freely offered, did not attempt them. The French built them one by one, as certain custom-built and highly expensive automobiles are produced. When American factories proposed, not only to produce French recuperators, but to manufacture them by making parts and assembling them according to the modern practice of quantity production, the ranks of the skeptics increased. Yet, as we have said, the thing was done. The first of the recuperators ever produced outside the French industry were produced in America and manufactured by typically American quantity methods.

The first of these recuperators to come into quantity production was that for the 155-millimeter howitzer. Rough forgings began to be turned out in heavy quantities by the Mesta Machine Company in the spring of 1918; the Watertown Arsenal, the other contractor, reached quantity production in rough forgings in August, 1918. At their special recuperator

plant at Detroit the Dodge Brothers turned out the first finished 155-millimeter howitzer recuperator in July, 1918, and went into quantity production in September, producing 495 in the month of November alone, and turning out in all the great number of 1,601.

Next in order of time to be conquered as a factory problem was the 155-millimeter gun recuperator. The rough forgings at the Carnegie Steel Company, the sole contractor, were in quantity production in the spring of 1918. The first of these recuperators to be finished came from the Dodge plant in October, 1918; and although thirty issued from the plant and were accepted before the end of the year, quantity production may be said to have started on January 1, 1919, when the factory began producing them at the rate of more than four a day. In March the high mark of 361 recuperators was reached. The total production was 881.

The heavy 240-millimeter howitzer recuperator was third to come into quantity production. The rough forgings were being turned out in quantity in the spring of 1918 by the Carnegie Steel Company; and the Watertown Arsenal, the other contractor, produced a number in October, 1918. The two contractors for finishing and turning out the complete recuperators were the Otis Elevator Company, at its Chicago plant, and the Watertown Arsenal. The arsenal produced the pilot recuperator in October, 1918. In January the Otis Elevator Company produced its first four; and quantity production began in February, 1919, both contractors that month sending out sixteen recuperators, a number which may be regarded as good quantity when the size of this mechanism is taken into consideration.

Last to come through to quantity production was the hardest of the four to build, the one that had threatened to defy American industry to build it at all—the 75-millimeter gun recuperator. The two principal contractors for the rough forgings for this recuperator were the Carbon Steel Company and the Bucyrus Company. The Carbon Steel Company was in large series production in the spring of 1918, and the Bucyrus

Photo from Dodge Brothers

IN THE 155-MILLIMETER RECUPERATOR PLANT

Photo from Otis Elevator Company

MAKING 240-MILLIMETER RECUPERATORS

Photo from Ordnance Department

FRENCH 75 MADE IN U. S. A.

Photo from Ordnance Department

AMERICAN-BUILT 155-MILLIMETER GUN

Company reached the quantity basis of manufacture in September, 1918. In that month alone the contractors turned out 748 sets of forgings.

The machining and finishing of the 75-millimeter recuperator were in the hands of the Rock Island Arsenal and the Singer Manufacturing Company, which built a costly plant especially for the purpose at Elizabethport, New Jersey. The first recuperator of this size to appear and be accepted under the severe tests came from the arsenal in November. Thereafter the production ceased for a while. The contractors indeed built recuperators in this period, but the recuperators could not pass the tests. The machining and production of parts seemed to be as perfect as human skill could accomplish, but still the devices would not function perfectly. Adjustments, seemingly of the most microscopical and trivial sort, had to be made—there was trouble with the leather of the valves and with oil for the cylinders. These matters, which could scarcely cause any delay at all in the production of less delicate machinery, indicate the infinite care which had to be employed in the manufacture of the recuperators. At length the producers smoothed out the obstacles and learned all the secrets and necessary processes, and then the 75-millimeter recuperators began to come—two in January, 1919, and then thirteen in February, twenty in March, and twenty in April. In July, 1919, the two contractors turned out 232 recuperators.

It should be remembered that by quantity production in this particular is meant the production in quantity of recuperators of such perfect quality as to pass the inspection of the Government and to be accepted as part of our national ordnance equipment. In its inspection the Government was assisted by French engineers sent from the great artillery factories in France which had designed the recuperators and which, until the successful outcome of the American attempt, were their sole producers. Such inspection naturally required that the American recuperators be the equals of their French prototypes in every respect.

Because the production of French recuperators stands at

the summit of American ordnance achievement, here at this point, before there is given any account of the manufacture of field artillery, the theme of this chapter, we insert a performance table to show the records written by the various concerns engaged in making these devices.

In discussing here the production of field artillery in the war period, we are concerned chiefly with carriages and recuperators, for they offered the major difficulties. Since the production of gun bodies for these various units has been taken up in the preceding chapter, such reference to them as is necessary will be brief. For the sake of additional clearness in the mind of the reader inexpert in these things, the line should be sharply drawn between field artillery and the so-called railway artillery, which was also mobile to a limited degree. The mobile field artillery consisted of all rolling guns or caterpillar guns up to and including the 240-millimeter howitzer in size; it also included the anti-aircraft guns of various sizes. All mobile guns of larger caliber than the 240-millimeter howitzer were mounted on railroad cars.

The list of the mobile field-artillery weapons in manufacture here during the war period was as follows:

The little 37-millimeter gun, the so-called infantry cannon, which two husky men could lift from the ground—a French design;

The 75-millimeter guns—three types of them—the French 75, adopted bodily by the United States; our own 3-inch gun, redesigned to the French caliber; and the British 3.3-inch gun, similarly redesigned;

The 4.7-inch gun of American design;

The 5-inch and 6-inch guns, taken from our coast defenses and naval stores and placed on mobile mounts;

The 155-millimeter gun, a French weapon with a barrel diameter of approximately 6 inches;

The 155-millimeter howitzer, also French;

The 8-inch and 9.2-inch howitzers, British designs, being manufactured in the United States when war was declared;

Total to Nov. 11, 1918	Total to Dec. 31, 1919
2,566	3,835
456	751
42	42
3,064	4,628
0	247
1	552
1	799
4,062	4,255
282	346
4,344	4,601
743	1,601
1,418	1,734
1	881
663	710
21	21
684	731
	277
1	148
1	425

litzer recuperators, all
m. howitzer recupera-

The 240-millimeter howitzer, French and American; and, finally,

The anti-aircraft guns.

In modern times, but prior to 1917, the United States had designed types of field-artillery weapons and produced them in quantities shown by the following tabulation:

	Pieces
2.95-inch mountain gun	113
3-inch gun	544
4.7-inch gun	60
5-inch gun	70
6-inch howitzer	40
7-inch howitzer	70
Total	897

A comparison of this list with the enumeration above of weapons put in production during the war against Germany indicates that we greatly expanded our artillery in types. That we were able to do this at the outset and go ahead immediately with the production of many weapons strange and unknown to our experience, without waiting to develop models and types of our own, is due solely to the generosity of the governments of France and Great Britain, with whom we became associated. We manufactured, in all, eight new weapons, taking the designs of three of them from the British and of five from the French.

It might seem to the uninitiated that the way of the United States to the great output of artillery would be made smooth by the action of the British and French governments in agreeing to turn over to us without reservation the blue prints and specifications which were the product of years of development in their gun plants. Yet this was only relatively true. In numerous instances we were not able to secure complete drawings until months after we had entered the war. The practice of continental manufacturers entrusts numerous exact measurements to the memories of the mechanics in their shops;

and it required several months to complete the drawings. Even when we received them, our troubles had only begun.

First, there came the problem of translating the plans after we received them. All French dimensions are according to the metric system. A millimeter is one one-thousandth part of a meter, and a meter is 39.37 inches. An inch is approximately .0254 meters. Thus, to translate French plans into American factory practice involves hundreds of mathematical computations, most of them carried out to decimals of four or five places. Moreover, the French shop drawings are put down on an angle of projection different from that used in this country. This fact involved the recasting of drawings, even when the metric system measurements were retained. When it is considered that such a mechanism as the recuperator on the 155-millimeter gun involves the translation of 416 drawings, the fact that the preparation of French plans for our own use never took more than two months is remarkable; particularly so because it was hard to find in the United States draftsmen and engineers familiar with such translation work.

Once our specifications were worked out from the French plans, it became necessary to find American manufacturers willing to bid on the contracts. The average manufacturer would look at these specifications, realize what a highly specialized and involved sort of work would be required in the production of the gun carriages or recoil mechanisms, and shake his head. In numerous instances no such work had ever before been attempted in the United States. But, as the result of efforts on the part of the Government, an increased capacity for producing mobile field artillery was created as follows:

At Watertown, New York, the New York Air Brake Company, as agent for the United States, constructed a completely new factory to turn out twenty-five carriages a month for the 75-millimeter guns, Model 1916—the American 3-inch type modified to the French dimensions.

At Toledo, Ohio, increased facilities were put up at the plant of the Willys-Overland Company to manufacture a

daily output of seventeen French 75-millimeter gun carriages, model 1897.

At Elizabethport, New Jersey, the Singer Manufacturing Company erected for the Government a complete new factory for finishing daily seventeen French 75-millimeter recuperators.

At New Britain, Connecticut, the plant of the New Britain Machine Company was adapted and increased facilities were created for the manufacture of two 3-inch anti-aircraft gun carriages a day.

At Detroit, Michigan, the Dodge Brothers, as agents for the Government, erected an entirely new factory, costing in the neighborhood of $11,000,000, to give the final machining to the rough-machine forgings for five recuperators daily for the 155-millimeter gun and to machine completely the parts for twelve recuperators daily for the 155-millimeter howitzer. Their huge new plant for this purpose established a record for rapidity of construction in one of the most severe winters of recent history.

At the plant of the Studebaker Corporation at Detroit, facilities were extended for turning out three carriages a day for the 4.7-inch guns.

At Plainfield, New Jersey, extended facilities were created at the factory of the Walter Scott Company for manufacturing twenty carriages a month for the 4.7-inch guns.

At Worcester, Massachusetts, at the plant of the Osgood Bradley Car Company increased facilities were built for the daily manufacture of five carriages for the 155-millimeter howitzers.

At Hamilton, Ohio, at the works of the American Rolling Mill Company, extensions were made to provide for the manufacture each day of three carriages for the 155-millimeter howitzers.

The plant of the Mesta Machine Company, at West Homestead, Pennsylvania, near Pittsburg, was extended to the enormous capacity for turning out the forgings for forty recuperators a day for 155-millimeter howitzers.

Extensively increased facilities were made at the shops of the Standard Steel Car Company, at Hammond, Indiana, for the daily output of two carriages for the 240-millimeter howitzers.

Increased facilities were created in the plant of the Otis Elevator Company, Chicago, Illinois, for the finish machining of the equivalent in parts of two and one-half recuperators a day for 240-millimeter howitzers.

Large extensions were made to the plant of the Morgan Engineering Company, Alliance, Ohio, for the manufacture monthly of twenty improvised mounts for the 6-inch guns taken from the seacoast fortifications.

The facilities of the United States arsenals at Watertown, Massachusetts, and at Rock Island, Illinois, for the manufacture of field-gun carriages and recuperators were greatly increased.

This carriage construction for the big guns required the closest kind of fine machine work and fittings where the brake or recuperator construction entered the problem, and the great plants built for this purpose of turning out carriages and recuperators were marvels for the rapidity of their construction, the speed with which they were equipped with new and intricate tools, and the quality of their output.

Every mobile gun mount must be equipped with a shield of armor plate. The size of the artillery project may be read in the fact that our initial requirement for armor for the guns ran to a total of 15,000 tons, to be produced as soon as it could be done. Now, we had no real source for getting armor in such large quantities, because the previous demands of our artillery construction had never called for it. The prewar manufacturers of artillery armor were three in number—the Simmons Manufacturing Company, of St. Louis; Henry Disston & Sons, of Philadelphia; and the Crucible Steel Company. To meet the new demand two armor sources were developed—the Mosler Safe Company plant of the Standard Ordnance Company and the Universal Rolling Mill Company. The process of building this armor had been a closely guarded

secret in the past—a fact which necessitated extended experiments in the new plants before satisfactory material could be obtained.

The new artillery program required the manufacture of 120,000 wheels of various types and sizes for the mobile carriages. The Rock Island Arsenal and two commercial concerns had been building artillery wheels in limited quantities before the war. One completely new plant had to be erected for the manufacture of wheels, and seven existing factories were specially equipped for this work. We had to develop new sources of supply of oak and hickory and to erect dry kilns specially for the wheel project.

The largest single order for rubber tires in the history of the American rubber industry was placed, as one relatively small phase of the artillery program, the order amounting to $4,250,000. Rubber tires on the wheels of all the heavier types of artillery carriages, so that the units might be drawn at good speed by motor vehicles, was essentially an American innovation. No tires of this size had ever been manufactured in this country, and it was necessary for the firms who got the orders to build machinery specially designed for the purpose.

With practically all the manufacturers of the American metal-working industries clamoring for machine tools, and with some branches of the Government commandeering the machine-tool shops in whole sections of the country, it is evident that the necessity for the heavier types of machine tools required by the manufacturers of artillery material offered a weighty problem at the outset. In fact, the machine-tool supply was never adequate at any time, and the shortage of this machinery hampered and considerably impeded the speed of our artillery production.

The nation was raked with a fine-toothed comb for shop equipment. The Government went to almost any honorable length to procure the indispensable tooling. For instance, when the Dodge plant at Detroit was being equipped to manufacture the 155-millimeter recuperators the government agents discovered several trainloads of machinery consigned to the

Russian Government and awaiting shipment. These tools were commandeered on the docks. One huge metal planer had dropped overboard while it was being lightered to the ocean tramp steamer that was to carry it to a Russian port. Government divers fixed grappling hooks to this machine, and it was brought to the surface and shipped at once to the Dodge plant.

The 3-inch gun which we had been building for many years prior to the war was a serviceable and efficient weapon; but still we were unable to put it into production immediately as it was. Our earliest divisions in France, under the international arrangement, were to be equipped by the French with 75-millimeter guns; while we on this side of the water, reaching out for all designs of guns of proved worth, expected to manufacture the 75's in large numbers in this country. The French 75 is a fraction of an inch smaller in its barrel diameter than our 3-inch gun, the exact equivalent of 75 millimeters being 2.95275 inches. Thus, if we built our own 3-inch gun (and the British 3.3-inch gun, as we intended) and also went ahead with the 75-millimeter project on a great scale, we should be confronted by the necessity of providing three sorts of ammunition of almost the same size, with all the delays and confusion which such a situation would imply. Consequently we decided to redesign the American and British guns to make their bores uniformly 75 millimeters, thus simplifying the ammunition problem and making available to us in case of shortage the supplies of shell of this size in France.

With all the above considerations in mind, it is evident now, and it was then, that we could not hope to equip our Army with American-built artillery as rapidly as that Army could be collected, trained, and sent to France; and this was particularly true when, in the spring of 1917, the army policy was changed to give each 1,000,000 men almost twice as many field guns as our program had required before that date. When, on June 27, 1917, the Secretary of War directed the Chief of Ordnance to provide the necessary artillery for the 2,000,000 men who were to be mobilized in 1917 and the first half of

1918, the first thought of our officers was to find outside supplies of artillery which we could obtain for an emergency that would not be relieved until our new facilities had reached great production.

We found this source in France. The French had long been the leading people in Europe in the production of artillery, and even the great demands of the war had not succeeded in utilizing the full capacity of their old and new plants. Two days later, on June 29, 1917, the French high commissioner, by letter, offered us in behalf of France a daily supply of five 75-millimeter guns and carriages, beginning August 1, 1917. The French also offered at this time to furnish us with 155-millimeter howitzers; and on August 19, 1917, the French Government informed General Pershing that each month, beginning with September, he could obtain twelve 155-millimeter Filloux guns and carriages from the French factories.

Before the signing of the armistice 75-millimeter guns to the number of 3,068 had been ordered from the French, and of this number 1,828 had been delivered. Of 155-millimeter howitzers, 1,361 had been ordered from the French and 772 delivered before November 11, 1918. Of 155-millimeter guns, 577 had been ordered and 216 delivered.

From British plants we ordered 212 Vickers-type 8-inch howitzers and 123 had been delivered before the armistice had been signed; while of 9.2-inch howitzers, Vickers model, 40 of an order for 132 had been completed. In addition to these, 302 British 6-inch howitzers were in manufacture in England for delivery to us by April 1, 1919. These figures, with the exception of those relating to the order for British 6-inch howitzers, do not include the arrangements being made by our Government during the last few weeks of hostilities for additional deliveries of foreign artillery.

As to our own manufacture of artillery, when we had conquered all the difficulties—translated the drawings, built the new factories, equipped them with machine tools and dies, gauges, and other fixtures needed by the metal workers, and had mobilized the skilled workers themselves—we forged

ahead at an impressive rate. When the armistice was signed we were turning out 412 artillery units a month. Compare this with Great Britain's 486 units a month in the fall of 1918 and measure our progress, remembering that England had approximately three years' head start. Compare it with the French monthly production of 659 units per month, and remember that France was the greatest artillery builder in the world. When it came to the gun bodies themselves, we obtained a monthly output of 832, as against Great Britain's 802 and France's 1,138. And our artillery capacity was then, in the autumn of 1918, only coming into production!

In the war period—April 6, 1917, to November 11, 1918—we produced 2,008 complete artillery units, as against 11,056 turned out by France and 8,065 by Great Britain in the same period. In those nineteen months we turned out 4,275 gun bodies. In the same months France produced 19,492 and Great Britain 11,852. (See Figure 13, page 40.)

37-MILLIMETER INFANTRY FIELD GUNS

The smallest weapon of all the field guns we built was the French 37-millimeter gun. The diameter of its bore is about one and one-half inches in our measurement; the exact figure is 1.45669 inches. This was the so-called infantry field gun, to be dragged along by foot soldiers making an advance. Its chief use in the war was in breaking up the German concrete pill boxes, machine gun nests, and other strong points of enemy resistance. In service it was manned by infantrymen instead of artillerists, a crew of eight men handling each weapon, the squad leader being the gunner. One of the men of the crew was the loader, and he was likewise able to fire the piece. The other six men served as assistants.

The 37-millimeter outfit consisted of the gun, with a split trail, mounted on axle and wheels. By means of a trailer attachment on the ammunition cart it could be drawn by one horse or one mule. The ammunition cart itself was merely a redesigned machine gun ammunition vehicle. The wheels and

axle could easily be removed and left a short distance in the rear of the place where it was desired to set up the gun. The whole outfit weighed only 340 pounds and was only about six feet long.

The gun rested on its front leg, which was dropped to form a tripod with the two legs of the split trail. The gun proper could be removed from the trail, and the sponge staff could be inserted in the barrel through the opened breech. Two men could bear this part of the weapon in advancing action. Two other men were able to carry the trail, when its legs were locked together, while four other members of the squad brought along the boxes of ammunition.

The ammunition cart held fourteen ammunition boxes, each containing sixteen rounds. A spare-parts case, strapped to the trail, contained a miscellaneous assortment of such parts as could readily be handled in the field. A tool kit in a canvas roll was also transported on the cart, along with entrenching tools and other accessories.

Equipped with a telescopic sight for direct fire and a quadrant, or collimating, sight for indirect fire, this small piece of artillery attained great accuracy. The length of the barrel of the gun proper was twenty calibers, which means that it was twenty times thirty-seven millimeters in length, or about twenty-nine inches. The length of the recoil when the gun was fired was eight inches.

Two types of ammunition were at first provided for this gun; but as the low-explosive type was not so effective as desired, it was abandoned entirely in favor of the high-explosive type contained in a projectile weighing one and one-fourth pounds. This projectile was loaded with 240 grains of T. N. T. and detonated by a base-percussion fuse. The range of the gun was 3,500 meters, or considerably more than two miles. Only three to six shots from it were found to be necessary to demolish an enemy machine gun emplacement or other strongly held position.

In the World War the 37-millimeter gun found itself and proved its usefulness. The original model had been designed

at the Puteaux Arsenal in France in 1885; but it was not until after 1914 that the weapon was produced in quantities.

In this country we took up the production of 37-millimeter guns in October, 1917. While our shops were tooling up for the effort, 841 of these weapons were purchased from the French and turned over to the American Expeditionary Forces. For greater speed in manufacture, our executives took the gun apart and divided it into three groups, known as the barrel group, the breech group, and the recoil group. Additional to these, as a manufacturing proposition, were the axle and wheels and the trail.

The barrel group went to the Poole Engineering & Machine Company, of Baltimore, Maryland, who subcontracted for some of the parts to the Maryland Pressed Steel Company, of Hagerstown, Maryland. The breech group was manufactured by the Krasberg Manufacturing Company, of Chicago. The C. H. Cowdrey Machine Works, of Fitchburg, Massachusetts, turned out the recoil mechanisms. The axles and wheels were built by the International Harvester Company, of Chicago. The trails were turned out by the Universal Stamping & Manufacturing Company, also of Chicago.

When crated for overseas shipment, the gun, ammunition cart, and all accessories weighed 1,550 pounds, and occupied about fifteen cubic feet of space.

The first delivery of completed 37-millimeter guns from our factories was made in June, 1918, and at the cessation of hostilities manufacturers were turning out the guns at the rate of ten a day. Between June and November 122 American-built 37-millimeter guns were shipped abroad, and more were ready to be sent over when the armistice was signed. The gun had been so successful in use abroad that our original order for 1,200 had been increased to 4,025 before the signing of the armistice.

The various groups of this gun were shipped to the plant of the Maryland Pressed Steel Company, Hagerstown, Maryland, for assembly and were there tested at a specially built proving ground, eight miles from the factory.

Three 37's were issued to each infantry regiment—one for each battalion. The required equipment for a division was, therefore, twelve weapons.

Production of 37-millimeter Guns

MODEL 1916 INFANTRY-ACCOMPANYING GUN

Guns procured from French Government	841
Total number ordered manufactured in United States	4,025
Total number completed at signing of armistice	826
Number delivered for overseas shipment at signing of armistice	300
Number canceled on United States orders	2,825
Total number completed on United States orders	1,200

MODEL 1916 GUN MODIFIED FOR TANKS AND MODEL 1918 SEMI-AUTOMATIC TANK GUN

Total number ordered manufactured in United States	2,438
Total number completed at signing of armistice	0
Number delivered for overseas shipment at signing of armistice	0
Number canceled	1,236
Total number modified for tanks completed, Model 1916	1,200
Total number semi-automatic, Model 1918, completed	2

75-MILLIMETER GUNS

NEXT in order in the upward scale of sizes we come to the 75-millimeter gun, which was by far the most useful and most used piece of artillery in the World War. In fact, the American artillery program might be divided into two classes, the 75's in one class, and all other sizes in the other, for it may practically be said that, for every gun of another size produced, we also turned out a 75. In number the 75's made up almost half our field artillery. The 75-millimeter gun threw projectiles weighing between twelve and sixteen pounds, and it had an effective range of over five and one-half miles.

We approached the war production of this weapon with three types available for us to produce—our own 3-inch gun;

its British cousin, the 3.3-inch gun, or 18-pounder; and the French 75-millimeter gun, with its bore of 2.95275 inches. The decision to adopt the 75-millimeter size and modify the other two guns to this dimension, giving us interchangeability of ammunition with the French, was an historic episode in the American ordnance development of 1917.

While, in 1917, the French, with their excess manufacturing capacity, were working on our first orders for 1,068 guns of this size, to supply our troops during the interim to elapse until American factories could come into production, we were preparing our factories for the effort. Roughly speaking, the 75 consists of a cannon mounted on a two-wheeled support for transportation purposes. This support also provides a means for aiming by suitable elevating and traverse mechanisms. As previously explained, a recoil mechanism is also provided to absorb the shock of firing, allowing a certain retrograde movement of the cannon and then returning it to position for the next shot—returning it "into battery," as the artillerists say. By its recuperator device the field gun of to-day is chiefly distinguished from its progenitor of the latter part of the nineteenth century. Without a recuperator the gun would leap out of aim at each shot and would have to be pointed anew; but one with a recuperator needs to be pointed only at the beginning of the action.

When we entered the war we found ourselves with an equipment of 544 field guns of the old 3-inch model of 1902. This gun had a carriage with the old-style single trail. By 1913, however, we had been experimenting with the split trail, and it had been strongly recommended by our ordnance experts; and in 1916 we had placed orders for nearly 300 carriages of the split-trail type, which had come to be known as Model 1916. Of these orders ninety-six carriages were to come from the Bethlehem Steel Company, and the remainder from the Rock Island Arsenal.

Meanwhile, for some time the Bethlehem Steel Company had been engaged in turning out carriages for the British 3.3-inch guns. Here was capacity that might be utilized to the

limit; and, accordingly, in May, 1917, we ordered from the Bethlehem Company 268 of the British carriages. At the same time we ordered from the same company approximately 340 of our own Model 1916 carriages, at a cost of $3,319,800. A few weeks later the decision had been made to make all our guns of this sort to conform to the French 75-millimeter size, and these British and American carriages, contracted for in May, were ordered modified to take 75-millimeter guns. The carriages needed little modification and the guns not much. Subsequently we placed orders in rapid succession with the Bethlehem Steel Company, calling for the construction of an additional 1,130 of the British carriages, all of them to be adapted to 75-millimeter guns.

Next it was the concern of the Ordnance Department to find other facilities for manufacturing carriages for these weapons. The artillery committee of the Council of National Defense located the New York Air Brake Company as a concern willing to undertake this work; and in June, 1917, this company signed a contract to produce 400 American Model 1916 carriages at a cost of $3,250,000.

By December we had the drawings for the French carriages of this size and made a contract with the Willys-Overland Motor Car Company to produce 3,049 of them.

The manufacture of carriages for the 75's produced concrete results: our factories here were turning them out for us at the rate of 393 a month when the fighting ceased, and our contract plants in France were making 171 a month. In all, we received from American factories 1,221 carriages. At the rate of increase we should have been building 800 carriages a month by February, 1919.

We were thoroughly impressed with the difficulties attached to transplanting to this country the manufacture of French 75-millimeter recuperators. It was a question whether this device could possibly be built by any except the French mechanics, trained by long years in its production. At first it seemed that we could secure no manufacturer at all who would be willing to assume such a burden. Not until February, 1918,

were complete drawings and specifications of the recuperator received from France. At length the Singer Manufacturing Company, builders of sewing machines, consented to take up this new work, and on March 29 the company contracted to produce 2,500 recoil systems for the 75-millimeter gun carriages. In April, 1918, the Rock Island Arsenal was instructed to turn out 1,000 of these recuperators.

The production of gun bodies for the 75-millimeter units was quite satisfactory. The Bethlehem Company, the Wisconsin Gun Company, the Symington-Anderson Company, and the Watervliet Arsenal were the contractors who built the gun bodies. Gun bodies of three types, but all of the same 75-millimeter bore, were ordered—the American type (the modified 3-inch gun), the British type (the modified 3.3-inch gun), and the French type.

Our ordnance preparation would have given us enough 75's for the projected army of 3,360,000 men on the front in the summer of 1919, together with appropriate provision for training in the United States. Of the 75's built in this country, 143 units were shipped to the American Expeditionary Forces before the armistice went into effect. Meanwhile the French had delivered to our troops 1,828 units of this size. The total equipment of 75's for our Army in France from all sources thus amounted to 1,971 guns with their complete accessories.

4.7-INCH GUNS

In the 4.7-inch field gun, model of 1906, America took to France a weapon all her own. It was a proved gun, too, developed under searching experiments and tests. There were sixty of these in actual service when we entered the war. The 4.7-inch guns, with their greater range and power, promised to be particularly useful for destroying the enemy's 77-millimeter guns.

The carriage model of 1906 for the 4.7-inch gun is of the long recoil type, the recoil being seventy inches. The recoil is checked by a hydraulic cylinder, and a system of springs thereupon returns the gun to the firing position. The gun's maximum

Photo from Willys-Overland, Inc.

75-MILLIMETER GUN CARRIAGES READY FOR WHEELS

Photo from Willys-Overland, Inc.

ASSEMBLING 75-MILLIMETER GUN CARRIAGES

Photo from Osgood-Bradley Car Company

ERECTING TRAILS FOR 155-MILLIMETER HOWITZER CARRIAGES

Photo from Osgood-Bradley Car Company

MANUFACTURING CARRIAGES FOR 155-MILLIMETER HOWITZERS

elevation is 15 degrees, at which elevation, with a 60-pound projectile, the gun has a range of 7,260 meters, or four and one-half miles. With a 45-pound projectile a range of 8,750 meters, or nearly five and one-half miles, can be obtained at 15 degrees' elevation. It is possible to increase this range to about 10,000 meters, or well over six miles, by depressing the trail into a hole prepared for it, a practice often adopted on the field to obtain greater range. The total weight of the gun carriage with its limber is about 9,800 pounds.

An order for 250 4.7-inch carriages was placed with the Walter Scott Company, at Plainfield, New Jersey, July 12, 1917, upon the recommendation of committees of the Council of National Defense, who were assisting the Ordnance Department in the selection of industrial firms willing to accept artillery contracts. Of the 250 ordered from this concern forty-nine were delivered before the signing of the armistice.

The Rock Island Arsenal had also been employed previously in turning out 4.7-inch carriages; and the capacity of that plant, although small, was utilized. Under the date of July 23, 1917, the arsenal was instructed to deliver 183 carriages. Late in December, 1917, the Studebaker Corporation was given an order for 500. On September 30, 1918, Rock Island Arsenal was given an additional order for 120 carriages, and the Studebaker order was reduced to 380. Additional plant facilities had to be provided by both the Walter Scott Company and the Studebaker Corporation.

Up to November 11, 1918, a total of 315 carriages of the 4.7-inch type had been completed and delivered. These carriages included the recoil mechanism. In the month of October, 1918, alone, 113 were produced, and this rate would have been continued had the armistice not been signed.

Cannon for the 4.7-inch units were turned out at the Watervliet Arsenal and the Northwestern Ordnance Company, Madison, Wisconsin. Deliveries from the Watervliet Arsenal began in June, 1918, totaling ninety-six by Armistice Day; and the Northwestern Ordnance Company, starting its deliveries in August, completed fifty by the date of the armistice. Up to the

15th of November, sixty-four complete 4.7-inch units had been floated for our forces overseas.

Forgings for the 4.7-inch gun cannon were made by the Bethlehem Steel Company and the Heppenstall Forge & Knife Company, of Pittsburg, Pennsylvania. Owing to the great difference in cross section between muzzle and breech end of the jacket, great difficulty was experienced in the heat treatment of these forgings, particularly on the part of manufacturers who had had no previous experience in the production of gun forgings. In order to produce enough forgings to supply the finish-machining shops, an order for fifty jackets was later given to the Edgewater Steel Company of Pittsburg, Pennsylvania, where the jackets were forged. These were then sent to the Heppenstall Forge & Knife Company for rough machining and finally returned to the Edgewater Steel Company for heat treating. An order for 150 jackets was also given to the Tacony Ordnance Corporation. Shortly before the signing of the armistice, the jacket was redesigned so that the heavy breech end was forged separately in the shape of a breech ring; but this design was not produced.

It was desired to develop the 4.7-inch gun carriage to give it the characteristics of the split-trail 75-millimeter gun carriage, model of 1916, so that greater elevation and wide traverse could be obtained. The Bethlehem Steel Company was given a small order for thirty-six carriages of their own design prior to the war, and their pilot carriage had been undergoing tests at the proving ground. The design was, however, not sufficiently advanced to be used in the war.

5-INCH AND 6-INCH GUN MOUNTS

In the war emergency America sought to put on the front every pound of artillery she could acquire from any source whatsoever. Accordingly, before any of the manufacturing projects were even started, the Ordnance Department conducted a preparedness inventory of the United States to see what guns already in existence we might find that could be improvised for use as mobile artillery in France. The search discovered a

number of heavy cannon that could serve the purpose—part of them belonging to the Army, these being the guns at our seacoast fortifications; part belonging to the Navy, in its stores of supplies for battleships; and part of them being the property of a private dealer, Francis Bannerman & Son, of New York.

The guns for this improvised use were obtained as follows: From the Coast Artillery, a branch of the Army, we obtained ninety-five 6-inch guns, 50 calibers in length, and twenty-eight 5-inch guns, 44.6 calibers; from the navy stores came forty-six 6-inch guns, ranging from 30 to 50 calibers in length; from Francis Bannerman & Son, thirty 6-inch guns, 30 calibers long. This was a total of 199 weapons of great destructive power, awaiting only suitable mobile mounts to make them of valiant service on the western front. It was the task of the Ordnance Department to take these guns and, as swiftly as possible, mount them on field-artillery carriages of an improvised type that could most quickly be built.

Minor changes had to be made on many of the guns obtained in this manner in order to adapt them to use on field-artillery carriages. The various seacoast guns were retained as they were in length, because it was planned to return them eventually to the fortifications from which they had been taken. The navy guns, all of the 6-inch size, were shipped to the Watervliet Arsenal to be cut down to a uniform length of thirty calibers.

The need for speed in manufacture demanded that the carriages for these guns be of the simplest design consistent with the ruggedness required for field operations and the accuracy necessary for effectiveness. When tests of the first carriages produced were made it was found that requirements had been more than met.

Orders were placed on September 24, 1917, with the Morgan Engineering Company, of Alliance, Ohio, for seventy mounts for the 6-inch units. A few days later this number was increased to seventy-four; and on the 28th of September, 1917, the same company was given an order for eighteen additional

6-inch gun mounts and twenty-eight mounts for the 5-inch guns. Orders for limbers were placed with the same company on December 1.

It was soon discovered that big transport wagons would be required to carry the long 6-inch seacoast guns separately, because of their great weight. On February 15, 1918, the Morgan Engineering Company was ordered to build these necessary transport wagons.

Difficulties in securing skilled labor, necessary materials, and tools delayed production of these mounts, but the eighteen 6-inch gun mounts ordered September 28, 1917, were completed in March, 1918, and the twenty-eight 5-inch gun mounts ordered on the same date were finished in April. In August, 1918, the seventy-four 6-inch gun mounts were turned out. The production of an additional order for thirty-seven 6-inch gun mounts was just beginning when the armistice was signed.

The 6-inch gun carriage, bearing the gun, weighs about 41,000 pounds. A maximum range of over ten miles can be obtained by this weapon. The complete 5-inch gun unit weighs about 23,500 pounds and has a maximum range of more than nine miles. In understanding the difficulties that faced the Ordnance Department in building carriages for these guns, it should be recalled that these big weapons were originally built for fixed-emplacement duty and were therefore much heavier than mobile types. This fact complicated the problem of designing the wheeled mounts. The guns proved to be more difficult to maneuver than the lighter types.

155-MILLIMETER HOWITZERS

It is a testimony to the adaptability and skill of American industry that we were able to duplicate successfully in this country the celebrated 155-millimeter howitzer, before 1917 built only in the factory of its original designer, the great firm of Schneider et Cie., in France. This powerful weapon is a fine example of the French gun builders' art, in a country where the art of gunmaking has been carried to a perfection unknown anywhere else.

The history of the 155-millimeter howitzer dates back to the nineteenth century. In its development the French designers had so strengthened its structure, increased its range, and improved its general serviceableness, that in 1914 it was ready to take its place as one of the two most-used and best-known weapons of the Allies, the other being the 75-millimeter field gun. As thus perfected, the howitzer weighs less than four tons and is extremely mobile for a weapon of its size. It can hurl a 95-pound projectile well over seven miles and fire several times a minute. The rapidity of fire is made possible by a hydropneumatic recoil system that supports the short barrel of the gun and stores up the energy of the recoil by the compression of air. With the gun pointing upward at an angle of 45 degrees, the recoil mechanism will restore it into battery in less than 13 seconds. The carriage of the gun is extremely light, being built of pressed steel parts that incorporate many ingenious features of design to reduce the weight. The shell and the propelling charge of powder are loaded separately.

The American-built 155-millimeter howitzer was practically identical with that built in France. Any of the important parts of the American weapon would interchange with those which had come from the Schneider factory. We equipped the wheels of our field carriage, however, with rubber tires, and gave the gun a straight shield of armor plate instead of a curved shield.

In the spring of 1917 we bought the plans of the howitzer from Schneider et Cie. and began at once the work of translating the specifications into American measurements. This work monopolized the efforts of an expert staff until October 8, 1917.

In order to facilitate the reproduction here, we divided the weapon, as a manufacturing proposition, into three groups—the cannon itself, the carriage, and the recuperator or recoil system—and placed each group in the hands of separate contractors. There was, of course, the usual difficulty in finding manufacturers who were willing to undertake production of so intricate a device and who also possessed machine shops

with the equipment and talent required for such work, and in procuring for these shops the highly specialized machinery that would be necessary.

The American Brake Shoe & Foundry Company, of Erie, Pennsylvania, whose magnificent work in building a special plant has been described in the preceding chapter, took an order in August, 1917, for 3,000 howitzer cannon and by October, 1918, was producing twelve of them every day. The company turned out its first cannon in February, 1918, approximately six months after receiving the contract, having in the interim built and equipped a most elaborate plant. It is doubtful if the annals of industry in any country can produce a feat to match this.

In fact, the production of cannon by the Erie concern so outstripped the manufacture of carriages and other important parts for the howitzer that it was possible by September, 1918, for us to sell 550 howitzer bodies to the French Government. When the armistice was signed on November 11, 1918, the company had completed 1,172 cannon.

In November, 1917, we placed orders for 2,469 carriages for this weapon, splitting the order between the Osgood-Bradley Car Company, of Worcester, Massachusetts, and the Mosler Safe Company, of Hamilton, Ohio. Then followed a long battle to secure the tools and equipment, the skilled mechanical labor, and the necessary quantities of the best grades of steel and bronze, an effort in which the contracting companies were at all times aided by the engineers of the Ordnance Department. All obstacles were overcome and the first carriages were ready for testing in June, 1918. When the armistice was signed, 154 carriages had been delivered, and production was moving so rapidly that one month later this number had been run up to 230.

The limbers were manufactured by the Maxwell Motor Car Company, which had orders to turn out 2,575 of them. The first deliveries of limbers came in September, 1918, and seven a day were being turned out in October, a total of 273

having been completed by the day of the armistice. A month later the number of completed limbers totaled 587.

It was in the making of the recuperator systems that the greatest problems were presented. No mechanism at all similar to this had ever been made in this country. No plant was in existence in America capable of turning out such a highly complicated, precise, and delicate device. Finally, after much governmental search and long negotiation, the Dodge Brothers, of Detroit, motor car builders, agreed to accept the responsibility. In this effort they built and equipped the splendid factory, costing $10,000,000, described elsewhere.

This howitzer recuperator is turned out from a solid forging weighing 3,875 pounds, but the completed recuperator weighs only 870 pounds. Each cylinder must be bored, ground, and lapped, in this mechanical sculpture, to a degree of fineness and accuracy that requires the most painstaking care.

Difficulties of almost every sort were experienced with the forgings and other elements of the recuperators. The steel was analyzed and its metallurgical formulas were changed. The work of machining proceeded favorably until the very last operation—polishing the interior of the long bores to a mirror-like glaze and still retaining the extreme accuracy necessary to prevent the leakage of oil past the pistons. Such precision had theretofore been unknown in American heavy manufacture. Until the many processes could be perfected, the deliveries were held back.

Even with the delivery of the first recuperator, difficulties did not vanish. This mechanism has no adjustments which can be made on the field, but depends for its wonderful operation upon the extreme nicety of the relation of its parts. It required the alteration of certain small parts before the first trial models could be made to function.

But all obstacles and difficulties were finally overcome, and in the plant that had been erected during the bitter cold of one of our severest winters, and with almost entirely new machinery and workmen, production got under way, and the first recuperator was delivered early in July, 1918, nine months

after the contract had been signed. Production in quantity began to follow shortly after that month, and by November an average of sixteen recuperators a day was being turned out. Of the 3,714 recuperators contracted for, 743 had been finished when the armistice was signed.

The steel required for the recuperators in these 155-millimeter howitzers, and also for those of the 155-millimeter guns, was of special composition; yet all the forge capacity in this country was being utilized in other war manufacture. New facilities for the manufacture of these forgings had to be developed by increasing the capacity of the Mesta Machine Company of Pittsburg, until it could meet our requirements. The Government itself contracted for these forgings and supplied them to Dodge Brothers.

Each howitzer required some two hundred items of miscellaneous equipment, such as air and liquid pumps and other tools. These were purchased from many sources, and many of these contractors had just as much difficulty with the small parts as the larger firms had with the more important sections of the howitzers.

Many of the problems involved in turning out the complete unit could not be known or understood until they were met with in actual manufacture. Mechanical experts representing Schneider et Cie. were on hand at all times to help solve difficulties as they arose.

The Government turned to France for an auxiliary supply of carriages for the American-built howitzers, placing orders for 1,361 with French concerns. Of this number 772 had been completed when the armistice was signed, and the French expected soon to turn out the carriages at the rate of 140 per month. It should also be noted here that we placed an order in England for 302 British 6-inch howitzers, pieces very like the French howitzers. The British contract was to be completed April 1, 1919.

The various parts of the 155-millimeter howitzer were assembled into complete units and tested at the Aberdeen Proving Ground. After being assembled and tested, the whole

unit was taken apart and packed into crates specially designed for overseas shipment. One crate held two howitzer carriages with recuperators in less space than would have been occupied by one carriage on its wheels.

It will be noted that the first 155-millimeter howitzer body made in the country was delivered in February and the first recuperator in July. Before the recuperators were ready, the other parts of the howitzer had been proof-tried by using a recuperator of French manufacture.

During August and September, 1918, the first regiment equipped with 155-millimeter howitzers was made ready at Aberdeen. The big weapons were packed and on the dock for shipment overseas when the armistice was signed. These first ones were to be followed by a steady stream of howitzers. All arrangements had been made to assemble units and crate them for overseas at the Erie Proving Ground at Port Clinton, Ohio.

None of the 155-millimeter howitzers built here reached the American Expeditionary Forces, but French deliveries of the weapon up to the signing of the armistice totaled 747.

155-MILLIMETER G. P. F. GUNS

THE reproduction in the United States of the French 155-millimeter G. P. F. (the French designation) gun presents much the same story as that of the howitzer of equal size—a story of difficulties in translating plans, in writing into them the precision of finishing measurements that the French factory usually leaves to the skill of the mechanic himself; difficulties in finding manufacturers willing to undertake the work; difficulties in providing them with suitable raw materials and machinery, and, above all, in locating the necessary skilled mechanics.

This strange big monster of a weapon is of rugged design. The entire unit weighs 19,860 pounds. The gun has the extremely high muzzle velocity of 2,400 feet per second, a rate of propulsion that throws the 95-pound projectile 17,700 yards, or a little more than ten miles.

The wheels of the carriage have a double tread of solid rubber tire. By an ingenious arrangement a caterpillar tread can be applied to the wheels in a few minutes whenever soft ground is encountered.

The center of gravity of the unit is low. The wheels are of small dimensions and the cradle is trunnioned behind in such a fashion as to reduce the height of the cannon. The carriage has a split trail, which allows for a large clearance for recoil at a high elevation and for a large angle of traverse. The carriage, when traveling, is supported on semi-elliptical springs, as is also the carriage limber.

Two large steel castings make up the carriage of this unit. The bottom part of the carriage is supported by the axle, which carries the two sections of the split trail upon the hinge pins. The top part of the carriage is supported by and revolves upon the bottom carriage and carries, in trunnioned bearings, the recuperator. The principal difficulty in carriage manufacture was to obtain in this country the extremely large steel castings of light-section, high-grade steel.

The carriages, 1,446 in number, were ordered in November, 1917, from the Minneapolis Steel & Machinery Company. The first delivery of carriages was made in August, 1918, and in the last week of October they were being turned out at the rate of seven a day. Up to the armistice date 370 had been produced, of which sixteen had been sent overseas. We also placed orders in France for 577 of these carriages, of which 216 had been completed upon the signing of the armistice. The American monthly rate of production of carriages in October was 162.

The 155-millimeter gun itself is far from being simple to manufacture. It is of considerable length and is built of a number of jackets and hoops to give the required resistance to the heavy pressures exerted in firing, this being a high-velocity gun. Except for a slight change in the manner of locking the hoops to the jacket, our gun is identical with that of the French.

Orders for 2,160 cannon were given to the Watervliet

Arsenal and the Bullard Engineering Works, at Bridgeport, Connecticut, in November, 1917. The Bullard Engineering Works had to construct new buildings and to purchase and install special equipment and the Watervliet Arsenal had to extend its shops and also purchase and install much additional machinery—a job that took time at both places. The first deliveries of cannon came from Watervliet Arsenal in July, 1918. During October fifty-one cannon were delivered, and it seemed certain that by early in 1919 the projected eight cannon a day would be the rate attained. We shipped sixteen of the cannon overseas. By November 11 we had received seventy-one.

Limbers in the same quantity as the carriages were ordered from the Minneapolis Steel & Machinery Company, which produced a limber to accompany each one of its delivered carriages. This limber has an extremely heavy axle, similar to the automobile front axle. Its size and weight caused difficulty in obtaining it as a drop forging.

To the Dodge Brothers was assigned the task of producing the recuperators for this gun in their special plant. The 155-millimeter gun recuperators, however, were made secondary to the production of the recuperators for the 155-millimeter howitzers, which were the easier of the two sorts to build.

Forgings were available and work started on recuperators in April, 1918. No rapid completion of these intricate mechanisms was possible, however, as the first forgings encountered many delays in their machinings. In the cycle of operations, with everything speeded up to the limit, more than three months must elapse from the day the recuperator forging is received to the day when the completed mechanism can be turned over to the inspector as an assembled article. It was in October, 1918, that the first 155-millimeter gun recuperator was delivered. The factory expected to reach a maximum capacity of ten a day. After the armistice was signed the company's order was reduced to 881, which had all been completed by May 1, 1919.

In order to have recuperators available for use for the units

shipped from the United States minus these mechanisms, 110 rough-machined recuperator forgings were shipped to France, where the work of machining and completing was done.

The translation of the French plans for this weapon furnished one of the most difficult pieces of work undertaken by the Ordnance Department. Without counting the gun pieces, the carriage and limber are made up of 479 pieces, and the recoil mechanism has 372. A total of 150 mechanical tracings had to be made by our draftsmen for the carriage and test tools; 50 for the carriage limbers; 142 for the recoil mechanism; 74 for the tools and accessories—a total of 416. It was extremely difficult to secure draftsmen who could do this work, and the translation, accomplished in a few weeks, is regarded as a remarkable achievement.

The cannon for this gun were tested at the Erie Proving Ground and there packed for overseas shipment. We had many cannon and carriages awaiting shipment when the armistice was signed, the plan being to send them to France, where they would be equipped with recuperators.

8-INCH HOWITZERS

In the early days of the war the British designed an 8-inch field howitzer that proved itself on battle fields in France. Great Britain loaded her own plants with orders for this weapon and then turned to the United States for additional facilities. The Midvale Steel & Ordnance Company, at its plant at Nicetown, Pennsylvania, was manufacturing this unit for the British at the time we entered the war.

On April 14, 1917, eight days after we had formally announced our purpose of warring with Germany, an order for eighty of these 8-inch howitzers was placed with the Midvale Company. It was understood that production on our order was to be begun upon the completion of the British contract on which the Midvale Company was then engaged. The order included the complete units, with carriages, limbers, tools, and accessories, all to be built in accordance with British specifications.

Contracts for the trails were sublet by the Midvale Company to the Cambria Steel Company; for the wheels, to the American Road Machinery Company; for the limbers and firing platforms, to the J. G. Brill Company; and for the open sights, to the British-American Manufacturing Company. Panoramic sights for these guns were furnished by the Frankford Arsenal.

So satisfactorily did the production proceed that on December 13, 1917, the first of the 8-inch howitzers was proof-tried with good results. Early in January, 1918, the complete units began to come through at the rate of three a week, increasing to four in April and to six in May.

A subsequent contract with Midvale brought the total number of howitzers ordered from that plant up to 195. These weapons, of the model known as the Mark VI, were nearly all produced and accepted before the signing of the armistice, ninety-six of them being shipped overseas, with their full complement of accessories. Each completed unit cost in the neighborhood of $55,000. These weapons throw a 200-pound projectile 11,750 yards.

The progress of the war moved so swiftly, however, that there soon arose the need for artillery units of this same size, but with longer range. Accordingly a new design, known as the Mark VIII½, was brought out, with a range of over 13,000 yards. On October 2, 1918, we placed with the Midvale Company an order for 100 of these 8-inch howitzers, specifying carriages of the new, heavier type.

When we entered the war the Bethlehem Steel Company, at Bethlehem, Pennsylvania, was producing for the British Government a howitzer with a bore of 9.2 inches. The Bethlehem Steel Company expected to complete these British contracts in July, 1917. The 9.2-inch howitzer was approximately the same size as the 240-millimeter howitzer which we were getting ready to put into production. However, in our desire to utilize every bit of the production facilities of the country, we ordered 100 of the 9.2-inch howitzer units from the Bethlehem Steel Company and placed additional orders for 132 of

these units in England. The British concerns delivered forty howitzers before the armistice was signed.

240-MILLIMETER HOWITZERS

The scheme of production of the French 240-millimeter howitzers was entirely aimed at the year 1919; for even if American heavy manufacturing establishments had not been loaded with war orders, it would have been well-nigh impossible to turn out this mighty engine of destruction in quantities in any shorter period of time.

Although approximately the same size as the British 9.2-inch howitzer (the exact diameter of the bore of the 240 being 9.45 inches) and only a little larger than the 8-inch howitzer, the French gun was far more powerful than either. The 8-inch and the 9.2-inch howitzers had ranges in the neighborhood of six miles, their shell weighing from 200 to 290 pounds. The 240 hurled a shell weighing 356 pounds and carrying a bursting charge of between forty-five and fifty pounds of high explosive. Its range was almost ten miles.

We produced the 8-inch and the 9.2-inch howitzers to fill the gap during the two years which must elapse before we could get into quantity production with the 240's. The French and British governments, in the fall of 1917, asserted their ability to equip our first thirty combat divisions in 1918 with heavy howitzers, so that if our production came along in the spring of 1919 it would meet the requirements of the war situation. Consequently we planned to equip our first army of thirty divisions with 8-inch and 9.2-inch howitzers—equal numbers of each. Our second army of thirty divisions should be wholly equipped with 240-millimeter howitzers; and our expected production of these, being beyond our own contemplated needs, would serve to replace such 8-inch and 9.2-inch howitzers as had been lost in the meantime.

As we adapted it from the French Schneider model, the 240-millimeter howitzer consisted of four main parts—the howitzer barrel, the top carriage, the cradle with recoil mechanism, and the firing platform. Each of these four parts

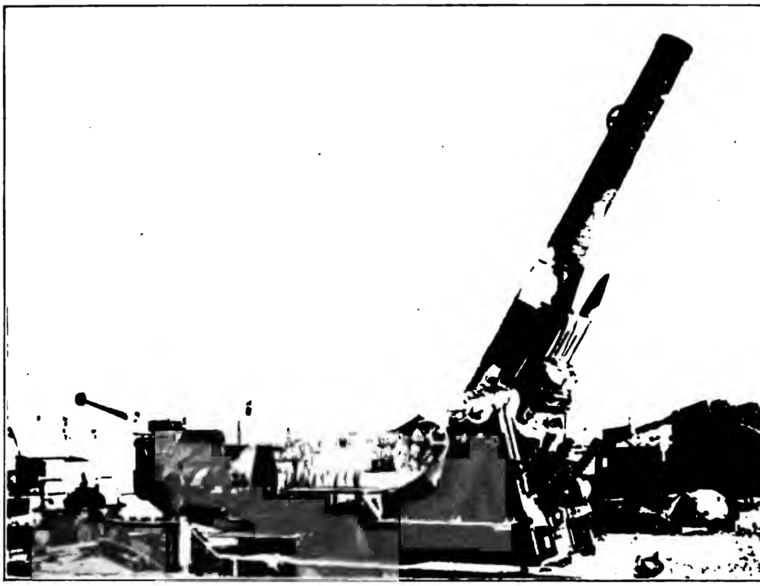


Photo from Ordnance Department

THE 240-MILLIMETER HOWITZER

Photo from Willys-Overland, Inc.

COMPLETED 75-MILLIMETER GUN CARRIAGES

Photo from Ordnance Department

CAISSONS ON SHIPPING PLATFORM

Photo from Willys-Overland, Inc.

SHIPPING 75-MILLIMETER GUN CARRIAGES

had its own transportation wagon and limber, drawn by a 10-ton tractor. The weapon was set up with the aid of an erecting frame and a small hand crane. Each of the main sections was composed of numerous smaller assembled parts made of various grades of iron and steel and other raw materials, all requiring the greatest precision in their manufacture and all having to pass rigid and exacting tests for strength and dimensions.

The production of even one of these enormous weapons would have been a hard job for any American industrial plant, but to manufacture nearly 1,200 of them, and that within the comparatively limited time allowed and under the abnormal industrial and transportation conditions then prevailing, was a task of tremendous difficulty and complexity.

On September 1, 1917, an order was placed with the Watertown Arsenal for 261 carriages for the American 240's, to be turned out complete with the recoil mechanism, transportation vehicles, tools, and accessories. An allotment of $17,450,000, set aside to cover the estimated expenses at the arsenal, indicates the size of the job. Well equipped as the Watertown Arsenal was said to be at the time for the production of heavy gun carriages, it was found necessary, in order to handle this job, to construct a new erecting shop of a capacity practically as large as that of all the other buildings of the plant put together. The number of employees at the arsenal was increased from 1,200 to more than 3,000. The greatest difficulty experienced was in obtaining the large number of heavy machine tools required, and experts were sent out to scour the country in an effort to locate these tools wherever they might be available. Raw materials could not be procured in sufficient quantities, and numerous transportation delays impeded the work. Finally, in October, 1918, the pilot carriage was completed, and sufficient progress had been made on the entire contract to assure production of the required number of units in the early part of 1919.

A second carriage contract (November 16, 1917) went to the Standard Steel Car Company, of Hammond, Indiana. This

called for the delivery of 1,004 carriages, complete with transportation vehicles, limbers, tools, etc., but not with recuperators. These the Otis Elevator Company, of New York, undertook to deliver. The Standard Steel Car Company is one of the most important builders of railway cars, freight and passenger, in the country, and it possessed a large and well-equipped plant. Nevertheless, the company was compelled to construct several additional buildings and practically to double the capacity of its huge erecting shop in order to prepare adequately for the tremendous task undertaken. To save time, subcontracts were immediately placed with more than a hundred firms throughout the East and Middle West for the production and machining of as many as possible of the component parts needed by the Standard Steel Car Company. Wherever practicable, the subcontractors working on similar contracts for the Watertown Arsenal were retained by the Indiana company, so that better prices might be obtained, parts standardized, and the whole production facilitated. Once the work was well under way, the ramifications of this one contract, with its subcontracts for parts, materials, tools, building construction, etc., extended throughout practically the entire industrial facilities of the eastern and central sections of the country.

As happened in connection with the contract given the Watertown Arsenal, there were many difficulties in obtaining tools and raw materials. Many allocations, mostly for iron and steel products, had to be obtained through the War Industries Board. When allocations had been granted, priority orders had to be secured, for the producers of these materials were already overworked with government orders of varying importance.

With the pilot carriage complete in the early part of October, production on all the main parts had progressed by November to such a point that a large output of finished carriages was assured for December and thereafter, had not the signing of the armistice ended the necessity for further expedition of the work.

Orders for howitzer-body forgings were placed as follows:

	Sets
Bethlehem Steel Company, November 21, 1917	237
Edgewater Steel Company, October 24, 1917	175
Tacony Ordnance Corporation, November 14, 1917	175
Watertown Arsenal, November 10, 1917	80
American Bridge Company, March 31, 1918	800

The Watervliet Arsenal was instructed on November 20, 1917, to do the machining of forgings so as to turn out 250 gun bodies for the 240-millimeter howitzers, and three months later this order was doubled. On November 7, 1918, an additional 660 were ordered from Watervliet, making a grand total of 1,160 howitzer cannon of this caliber ordered machined and completed at the Watervliet Arsenal. The arsenal contracted to reach an output of 100 cannon a month and to deliver the last of the 1,160 not later than September 30, 1919.

It was found necessary to erect an entirely new shop for the machining of these howitzers. This shop was completed in May, 1918. During the war period $13,164,706 was spent or allotted to the Watervliet Arsenal for increasing its facilities. Forgings were furnished to the arsenal by the Government, but the forging situation was never a delaying factor in the production of 240-millimeter howitzers.

In the summer of 1918 the Watertown Arsenal contracted to build 252 additional recuperators for these howitzers. Work was started at once in the shops, and, though additional facilities had to be prepared and much new equipment added, the production of the first recuperator was begun without delay. It was found that the planing equipment at the arsenal was not sufficient to handle the work, and therefore a great deal of the rough planing was done by subcontractors.

The Watertown Arsenal was to furnish its own forgings, but it was quickly found that an additional source of supplies was required. The Carnegie Steel Company had been given an order on December 27, 1917, for 1,300 recuperator forgings, and some of these were sent to the Watertown Arsenal. The first recuperator was completed October 28, 1918. The pilot

howitzer, minus the recuperator, went to the proving ground on August 24, 1918.

To handle its order for 1,039 recuperators, the Otis Elevator Company, of New York, found it necessary to rebuild a plant which it owned in Chicago. Forgings were furnished by the Government.

On May 1, 1918, the Otis Elevator Company started its rough machining. Hard spots found in the metal caused great trouble at first, but this difficulty was overcome by changes in the heat treatment. The Carnegie Steel Company was then instructed to rough-machine the forgings before sending them to the Otis Elevator Company. An order was also given to the Midvale Steel Company to rough-machine twenty-four forgings. Early in January, 1919, the Otis Elevator Company finished its first recuperator.

One 240-millimeter howitzer unit was completed at the time of the signing of the armistice; but had war conditions continued, the expectation was that the contractors by 1919 would reach a production rate of eighty complete units a month.

FIGHTING THE AIRPLANE WITH ARTILLERY

THE American development of anti-aircraft artillery had, previously to 1917, been confined almost exclusively to the task of designing and constructing stationary units of defense for our coast fortifications. It was naturally expected that at those points we should first, if ever, have to meet an attack from the air. Little attention had been paid to mobile artillery of this sort.

Before April, 1916, the Ordnance Department had designed a high-powered 3-inch anti-aircraft mount for fixed emplacement at coast fortifications. The gun on this mount fired a 15-pound projectile with a muzzle velocity of 2,600 feet a second. It was the most powerful anti-aircraft weapon of its caliber. Between May, 1916, and June 18, 1917, orders for 160 of these mounts were placed with the Watertown Arsenal and the Bethlehem Steel Company. Up to April 10,

1919, a total of 116 had been completed and sent for emplacement at the points selected.

By the end of 1916, however, it was foreseen that it would be necessary to provide anti-aircraft artillery of a mobile type as part of the equipment for any field forces that might be sent abroad. Since such a contingency seemed entirely possible at that time, and since it appeared to be impossible to provide a suitable design which would have sufficient time to receive proper consideration and test, it was decided to improvise a simple structural steel design which would permit quick construction and on which a 75-millimeter field gun, already in production, could be mounted. This design was completed May 1, 1917, and an order for fifty placed with the Builders' Iron Foundry. Deliveries on these were made during the fall of 1917, and the carriages were at once shipped to France to be equipped with French field guns and recuperators that had been already procured for the purpose.

In mobility the improvised anti-aircraft gun mount was far from perfect. It was necessary to disassemble it partly and mount it on trailers. The need for a mount that could be moved easily and speedily had been realized before our entrance in the war, and a design embodying these qualities was completed as early as December, 1916. This truck was designed to be equipped with the American 75-millimeter field gun, model of 1916. Before the drawings were completed an order for the pilot mounts of this type was placed with the Rock Island Arsenal. The war came on, and it was decided not to wait for a test of the mounts before starting general manufacture. Accordingly the New Britain Machine Company, in July, 1917, was given an order for fifty-one carriages. No further orders were placed for carriages of this sort, as it was not thought best to go too heavily into production of an untried mount.

It should be noted here that our first twenty-six anti-aircraft guns were mounted on White 1½-ton trucks.

It was also realized that the field guns with which these mounts were to be equipped did not have the power and range that war experience was showing to be necessary. The only

reasons why the field guns of the 75-millimeter caliber were used in this way was that they were the guns most quickly available and that the French were already using them for this purpose.

To meet the need of more powerful anti-aircraft weapons, a need becoming more pressing each day, a 3-inch high-powered anti-aircraft gun was designed and mounted on a four-wheel trailer of the automobile type. This mount permitted elevations of the gun from 10 degrees to 85 degrees and also allowed for "all-around" firing. An order for 612 of these carriages was given to the New Britain Machine Company in July, 1917, shortly after the contract for the fifty-one truck mounts had been placed with that concern.

Because of the urgency of the situation it was necessary to construct these carriages without the preliminary tests on a pilot carriage. This, of course, is an undesirable practice, but under the existing conditions no other procedure would have been practicable. The French anti-aircraft auto-truck mount, which carried the French 75-millimeter field gun, with its recuperator, placed upon a special anti-aircraft mount, was not adopted at the time, because, in July, 1917, the whole question of the possibility of constructing French recuperators in this country was still entirely unsettled. It was imperative then that we develop our own designs.

All the fifty-one truck mounts for the anti-aircraft guns were delivered during the fall and early winter of 1918, and twenty-two of them were in France before December, 1918.

Delivery of the first carriage for the 3-inch high-powered gun mounted on the trailer carriage was made in August, 1917. It had been rushed ahead of general production in order to be given some sort of test. No further deliveries were made, but the manufacture reached a point where production in quantity could soon begin.

A representative of the Ordnance Department was sent to France and England in December, 1917, to gather all the information possible about anti-aircraft artillery. As a result of his investigations it was determined that it would be best

to procure the greater part of our fire-control equipment in France, since some of the instruments developed there were highly complicated and their manufacture was entirely controlled by private persons. Orders were placed for enough of these instruments for the equipment of the first 125 batteries.

Production of Mobile Artillery (Complete Units), April 1, 1917, to November 11, 1918

[Including all produced for France and Great Britain in United States]

	Produced	Shipped overseas
75-mm. guns (or British 18-pounder)	970	181
3-inch and 75-mm. anti-aircraft guns	97	[1] 26
4.5-inch howitzers	97	97
4.7-inch guns	157	64
155-mm. and 5-inch and 6-inch seacoast guns	121	[2] 114
155-mm. howitzers	144	0
7-inch guns on caterpillar mounts	[3] 10	0
Railway artillery	20	11
Heavy howitzers	[4] 418	322
Total	2,034	815

[1] Does not include fifty-one improvised mounts for which guns were furnished by French.
[2] Includes sixteen 155-mm. guns and carriages shipped without recuperators.
[3] Built for the Marine Corps.
[4] Includes sixteen 8-inch howitzers built for the Marine Corps.

Meanwhile, fire-control instruments of various types were in the process of development in this country; but, as they were largely based upon theoretical construction derived from study of the French practices, it was deemed best not to manufacture any of them in quantity, when better instruments of French design were available. Drawings of the French instruments were available in this country in the spring of 1918, when manufacture of some of them began in the United States.

At the signing of the armistice our forces in France were

equipped almost wholly with anti-aircraft artillery loaned to us or supplied outright by the French. This equipment, of course, did not include the 101 improvised mounts completed during 1917. Our production, however, had reached such a point that shipment of material would have begun in quantity in January, 1919.

The estimated requirements in anti-aircraft artillery for an army of forty-eight divisions (2,000,000 men) were only 120 guns. Other anti-aircraft weapons were required in the defense of depots, railheads, etc., the number required depending in great measure upon the ability of our own air forces to keep the enemy bombers away. It is estimated that about two hundred anti-aircraft guns were required for the rear defenses of forty-eight divisions.

Sept.	Oct.	Nov.	Dec.	Total
113	30	72	...	799
15	...	...	...	363
...	...	...	...	909
...	...	...	...	51
2	7	3	...	256
1	1	...	...	417
...	...	...	...	28
...	...	...	...	92
...	...	...	...	625
29	24	16	19	492
...	...	...	...	245
...	...	...	...	1
29	20	25	7	182
189	82	116	26	4,460

onent parts were complete,
itional time.

In addition to these there was the 16-inch howitzer, 20 calibers in length, which had been built by the Ordnance Department before 1917.

The Ordnance Department conceived that the only way to make these guns available for use abroad was to mount them on railway cars. The guns were not vital to the defense of our coast under the conditions of the war with Germany, and it was evident that they would make a valuable type of long-range artillery when placed on satisfactory railway mounts.

Mounting heavy artillery on railway cars was not an idea born of the recent war. The idea was probably originally American. The Union forces at the siege of Richmond in 1863 mounted a 13-inch cast-iron mortar on a reinforced flat car. This was the first authenticated record of the use of heavy railway artillery. In 1913 the commanding officer of the defenses of the Potomac, which comprise Forts Washington and Hunt, was called on to report upon the condition of these defenses. In reply, he advised that no further expenditure be made on any one of the fixed defenses, but recommended that a "strategic railroad" be built along the backbone of the peninsula from Point Lookout to Washington, with spurs leading to predetermined positions both on Chesapeake Bay and the Potomac River, so placed as to command the approaches to Washington and Baltimore. Further, he recommended that four major-caliber guns, sixteen medium-caliber guns, and twenty-four mine-defense guns be mounted on railroad platforms, with ammunition, range-finding, and repair cars making up complete units, so that this armament could be quickly transported at any time where most needed. He suggested that this scheme be made applicable to any portion of the coast line of the United States. His argument was based upon the fact that guns in fixed positions, of whatever caliber, violate the cardinal military principle of mobility.

The nations engaged in the World War developed to a high stage the use of heavy artillery mounted on railway cars, bringing about a combination of the necessary rigidity with as great mobility as is compatible with the weight of this material.

Railway artillery came to be as varied in its design as field artillery. Each type of railway mount had certain tactical uses, and it was not considered desirable to use the different types interchangeably. The three types of cannon used on railway mounts were mortars, howitzers, and guns. It was not practicable to use the same type of railway mounts for the different kinds of cannon. Moreover, these mounts differed radically from the mounts for such weapons at the seacoast defenses.

The three general types of railway mounts adopted were those which gave the gun all-around fire (360-degree traverse), those which provided limited traverse for the gun, and those which allowed no lateral movement for the gun on the carriage, but were used on curved track, or epis, to give the weapons traverse aim. The smaller weapons, such as the 7-inch and 8-inch guns and the 12-inch mortars, were placed on mounts affording 360-degree traverse. The limited-traverse mounts were used for the moderately long-range guns and howitzers. The fixed type of mount was used for the biggest guns only, and included the sliding railway mounts, such as the American 12-inch and 14-inch sliding mounts and the French Schneider *à glissement* mounts.

The work of providing railroad artillery—that is, taking the big, fixed-position guns already in existence within the United States, and similar guns being produced, and designing and manufacturing suitable mounts for them on railway cars—grew into such an important undertaking that it enlisted the exclusive attention of a large section within the Ordnance Department. This organization eventually found itself engaged in ten major construction projects, which in time, had the war continued, would have delivered more than 300 of these monster weapons—most of them to the field in France and some to the railway coast defenses of the United States. As it was, so much of the construction—the machining of parts, and so on—was complete at the date of the armistice that it was decided to go ahead with all the projects except three, these latter involving the mounting of sixteen guns of 14-inch size, 50 calibers long, the production of twenty-five

long-range 8-inch guns, 50 calibers, and their mounting on railway cars, and the mounting of eighteen coast-defense 10-inch guns, 34 calibers long, on the French Batignolles type of railway mount.

Inasmuch as it will be necessary in this chapter to refer to the barbette, Schneider, and Batignolles types of gun mounts for railway artillery, it should be made clear to the reader what these types are.

The barbette carriage revolves about a central pintle, or axis, and turns the gun around with it. When it was decided to put coast-defense guns on railway cars, the guns were taken from their emplacements, barbette carriages manufactured for them, and the whole mounted upon special cars. The barbette mount revolves on a support of rollers traveling upon a circular base ring. In the railway mount the base ring is attached to the dropped central portion of the railway car. The barbette railway mount is provided with struts and plates by which the car is braced against the ground.

The Schneider railway mount is named after the French ordnance concern, Schneider et Cie., who designed it. In this mount the gun and its carriage are fastened rigidly parallel to the long axis of the railway car. Thus the gun itself, independently of any movement of the car, can be pointed only up and down in a vertical plane, having no traverse or swing from left to right. In order to give the weapon traverse for its aim, special curved tracks, called epis, are prepared at the position where it is to be fired. The car is then run along the curve until its traverse aim is correct, and the vertical aim is achieved by the movement of the gun itself. In the Schneider mount there is no recoil mechanism: the recoil is absorbed by the retrograde movement of the car along the rails after the gun is fired. This movement, of course, puts the gun out of aim, and the entire unit must then be pushed back to the proper point.

In the Batignolles type, gun and cradle are mounted on a so-called top carriage that permits small changes in horizontal pointing right and left. With railway artillery of the Bati-

gnolles type also, track curves, or epis, are necessary for accurate aiming. The Batignolles mount partially cushions the recoil by the movement of the gun itself in the cradle. In addition, a special track is provided at the firing point, and the entire gun car is run upon this track and bolted to it with spades driven into the ground to resist what recoil is not taken up in the cradle. The unit is thus stationary in action, and the gun can be more readily returned to aim than a gun on a Schneider mount.

7-INCH RIFLES

The conditions under which the war with Germany was fought virtually precluded any chance of a naval attack on our shores which would engage our fixed coast defenses. The British Grand Fleet, with the assistance of fleets of the other Allies and America, had the German battle fleet securely bottled. On the other hand, there was the prowling submarine, able at all times to go to sea and even to cross the ocean; and some of the latest of these submarines were armed with long-range medium-caliber guns. It was not beyond possibility that some sort of attack would be made on our shores by submarines of this scope; but it was safe to believe that these craft would keep well out of range of the guns at our stationary coast defenses.

To protect our coast from such attack, the Ordnance Department conceived the plan of mounting heavy guns on railway cars. They could then be moved quickly to places on the seacoast which needed defense. For this purpose the Navy turned twelve of its 7-inch rifles over to the Ordnance Department for mounting. Meanwhile our ordnance officers had designed certain standard railway artillery cars, known as models 1918, 1918 Mark I, and 1918 Mark II, for 7-inch and 8-inch guns and 12-inch mortars, respectively. All these cars had the same general features.

The Model 1918 car was selected for the converted 7-inch navy rifle. The rifle was mounted on a pedestal set on the gun car in such a manner as to give all-around fire, or 360-degree

traverse. The pedestal mount permitted the gun to be depressed to an angle suitable for firing from high places along the coast down upon the low-lying submarines.

Contracts for the various parts for these cars and the pedestal gun mounts were let to concerns engaged in heavy steel manufacture, but the assembling was done by the American Car & Foundry Company, of Berwick, Pennsylvania. Twelve of the 7-inch rifles were so mounted. As this equipment was intended exclusively for use in this country, the gun cars were equipped with the American type of car couplings.

8-INCH GUNS

For the 8-inch guns taken from seacoast fortifications the Ordnance Department designed a barbette mount giving complete 360-degree traverse. There were ninety-six such guns available for railway mounts. Orders for forty-seven gun cars, with carriages for mounting the weapons, were placed with three concerns—the Morgan Engineering Company, of Alliance, Ohio, the Harrisburg Manufacturing & Boiler Company, of Harrisburg, Pennsylvania, and the American Car & Foundry Company, of Berwick. Two of the three contractors found it necessary to provide additional facilities and machine-tool equipment at their plants in order to handle this job.

The first railway mount for the 8-inch gun was completed and sent to the Aberdeen Proving Ground for test in May, 1918. In early June the test had shown that the weapon was efficient and entirely satisfactory. Before the end of the year 1918 a total of twenty-four complete units, with ammunition cars for standard-gauge track, shell cars for narrow-gauge track, transportation cars, tools, spare parts, and all the other necessary appurtenances of a unit of this sort, had been completed. Three complete 8-inch units were shipped overseas before the armistice was signed.

When the armistice came, the Harrisburg company had delivered nine of these mounts and the Morgan Engineering Company an equal number—eighteen in all. The former con-

Photo from Ordnance Department

THE AMERICAN 7-INCH RAILWAY GUN

Photo from Ordnance Department

8-INCH RAILWAY GUN

Photo from Ordnance Department

12-INCH RIFLE ON SLIDING RAILWAY MOUNT

Photo from Ordnance Department

THE 16-INCH HOWITZER

cern had reached an output of five mounts a month and the latter ten a month.

An interesting feature of this mount is that it can be used either on standard-gauge or on narrow-gauge railroad track. The narrow gauge adopted was that in standard use in the fighting zones in France, the distance between the rails being sixty centimeters, or the approximate equivalent of twenty-four inches. Each gun car was provided with interchangeable trucks to fit either gauge. The artillery train necessary for the maneuvering of the weapon was also similarly equipped to travel on either sort of track.

As a rule, the longer the barrel of a cannon, the greater its range. The 8-inch seacoast guns thus mounted were 35 calibers in length; that is, thirty-five times eight inches, or 23 feet, 4 inches. The requirements of our forces in the field in France called for guns of this same size, but of longer range. Consequently an 8-inch gun of 50 calibers—that is, ten feet longer than the seacoast 8-inch gun—was designed, and twenty-five were ordered. This project came as a later development in the war, the guns being intended for use abroad in 1920. The railway mounts for the weapons had not been placed in production when the armistice came. Because of the incomplete status of this project in the autumn of 1918, the whole undertaking was abandoned.

10-INCH AND 12-INCH GUNS

There were at the seacoast defenses and in the stores of the Army a large number of 10-inch guns of 34 calibers. Of these, 129 were available for mounting on railway cars. It was proposed to mount these weapons on two types of French railway mounts—the Schneider and the Batignolles.

The project to mount thirty-six of these weapons on Schneider mounts was taken up as a joint operation of the United States and French governments, the heavy forging and rough machining to be done in this country and the finishing and assembling in the French shops. The American contractors were three. The Harrisburg Manufacturing & Boiler

Company undertook to furnish the major portion of the fabricated materials for the carriages and cars; the Pullman Car Company contracted to produce the necessary trucks for the gun cars; and the American Car & Foundry Company engaged to build the ammunition cars.

Eight sets of fabricated parts to be assembled in France had been produced before the armistice was signed. General Pershing had requested the delivery in France of the thirty-six sets of parts by March 2, 1919. After the armistice was signed there was a natural let-down in speed in nearly all ordnance factories, but even without the spur of military necessity the contracting concerns were able by April 7, 1919, to deliver twenty-two of the thirty-six sets ordered. Had the war continued through the winter, there is little question but that all thirty-six would have been in France on the date specified.

The 10-inch seacoast gun, Batignolles mount, project was placed exclusively in the hands of the Marion Steam Shovel Company, of Marion, Ohio. It had been proposed also to mount 12-inch seacoast guns on this same type of equipment, and this work, too, went to the Marion concern. There were to be produced eighteen of the 10-inch units and twelve of the larger ones. The Marion Steam Shovel Company had had a large experience in producing heavy construction and road-building equipment. The concern encountered numerous difficulties at the start in translating the French drawings and in substituting the American standard materials for those specified by the French. These difficulties, combined with struggles to obtain raw materials and the equipment for the increased facilities which had to be provided at the factory, so delayed production that no mount for either the 10-inch or 12-inch guns had been delivered at the time of the armistice. The first mount of these classes—one with a 12-inch gun—reached the Aberdeen Proving Ground about April 1, 1919. The 10-inch project, calling for eighteen mounts, was canceled soon after November 11, 1918. The work on the dozen mounts for 12-inch guns, however, had progressed so far that the Ordnance Department ordered the completion of the entire equipment.

As we have stated, the Government found in this country six 12-inch guns being made for the Republic of Chile. Their length of 50 calibers gave them a specially long range. It was decided to place the Chilean guns on sliding mounts. In a mount of this type, the retrograde movement of the car along the track as and after the gun is fired takes up and absorbs the energy of fire.

The first sliding railway mount used on the Allied side in the World War was of French design. But our manufacturers had so much trouble with French designs that, when the project of mounting the Chilean guns in this fashion came up, it was decided that it would be quicker to design our own mount. Consequently the French design was taken in hand by our ordnance engineers and redesigned to conform to American practice, with the inclusion in the design of all original ideas developed by the Ordnance Department in its creative work during the war period up to that time. The manufacturers who looked at the French design of the sliding railway mount estimated that it would take from twelve to eighteen months before the unit could be duplicated in this country and the first deliveries made. They looked at the American design and estimated that they could build it in three months.

It was decided to build three of these mounts, so as to have a reserve of one gun for each mount, to serve as replacement when the guns first mounted were worn out. Contracts were placed in the early summer of 1918, and all three mounts were delivered before the armistice was signed, the first mount being completed within eighty-five days after the order was placed. For these mounts the American Bridge Company furnished the main girders or side pieces, the Baldwin Locomotive Company built the railway trucks, and the Morgan Engineering Company manufactured the many other parts and assembled the complete units. The speed in manufacture was made possible by the fact that the plant engineers of the three companies helped the ordnance officers in designing the details. With such intimate coöperation, the concerns were able to begin the manu-

facture of component parts while the drawings were being made.

All three weapons, with their entire equipment, including supplies, spare parts, ammunition cars, and the whole trains that make up such units, were ready for shipment to France in November, 1918. Each mount was 105 feet long and weighed 600,000 pounds. The load of the gun and the peak load put on the carriage when the gun was fired were so great that it required four trucks of eight wheels each, thirty-two car wheels in all, to distribute the load safely over ordinary standard-gauge track.

12-INCH MORTARS

In years past, the Ordnance Department had procured a large number of 12-inch mortars for use at seacoast defenses. These great weapons are 10 calibers in length, or ten feet in linear measurement. Of the number stationed at the coastal forts and in reserve, it was decided that 150 could be safely withdrawn and prepared for use against Germany. When General Pershing was informed of the proposal, he asked that forty of these weapons, mounted on railway cars, be delivered to the American Expeditionary Forces for use in the planned campaign of 1919. In order that there might be an adequate supply of them, the Ordnance Department let contracts for the mounting of ninety-one of these mortars on railway equipment, a project calculated to give the United States a formidable armament and still provide a reserve of fifty-nine mortars to replace the service mortars on the carriages after repeated firing had worn them out.

This job proved to be one of the largest in the whole artillery program. The entire contract was let to the Morgan Engineering Company, of Alliance, Ohio. In order to handle the contract, a special ordnance plant, costing $1,700,000 for the building alone, had to be constructed at the company's works at Alliance. The work was so highly specialized that machine tools designed for the particular purpose had to be produced. The Government itself bought these tools at a cost of $1,800,-

000. Although work on this plant was not started until December 10, 1917, and although thereafter followed weeks upon weeks of the severest winter weather known in years, with all the delays in the deliveries of materials which such weather conditions brought about, the plant was entirely complete on June 1, 1918, and not only that, but the work of producing the mounts had started in it long before, some machines getting to work as early as April.

The gun car used for mounting the mortar carriage was of the same design as that for the 7-inch and 8-inch guns, except that each truck had six wheels. The carriage built upon this car was of the barbette type, and it allowed the gun to be pointed upward to an angle as high as 65 degrees and provided complete traverse, so that the mortar could be fired in any direction from the car. A hydropneumatic system for absorbing the recoil of the mortar after firing was adopted. This recuperator in itself was a difficult problem for the manufacturer to solve, for it was the first hydropneumatic recuperator of its size ever built in this country.

In spite of the weight and complexity of this unit, it was put into production in an astonishingly short space of time. The pilot mount came through on August 22, 1918, less than nine months after the spade was first struck into the ground to begin the erection of the ordnance plant. By the end of August the pilot mortar had successfully passed its firing tests at Aberdeen, functioning properly at angles of elevation from 22 degrees to 65 degrees and in any direction from the mount. This unit was put through hurriedly for these tests; but the preparation for the rest of the deliveries was made on a grand scale, looking toward quantity production later on. When the armistice was signed, every casting, forging, and structural part for every one of the ninety-one railway mounts was on hand and completed at the works of the Morgan Engineering Company, and thereafter the process was to be merely one of assembling, although in a unit of such size the assembling job alone was of great magnitude. Even at the reduced rate of production incident to the relaxation of tension after the armistice

was signed, the company delivered forty-five complete units to the Government up to April 7, 1919, or five more than General Pershing had said he would require during the whole campaign of 1919. Careful estimates show that if the war had continued the company would have delivered the mounts at the rate of fifteen a month beginning on December 15, 1918, a rate which would have completed the entire project for ninety-one mounts by the middle of June, 1919.

Like the 8-inch railway guns, the 12-inch mortars were provided with interchangeable wheel trucks which would allow the unit to travel and work either on standard-gauge track or on the 60-centimeter, narrow-gauge track of the war zone in France.

14-INCH GUNS

The War Department did not have any 14-inch guns which could be spared from the seacoast defenses for use abroad. The Ordnance Department therefore inaugurated the project for the construction of sixty guns of 14-inch caliber. For the construction of such guns, complete new plants were required, for all available facilities were already taken over for other projects considered more important. This contract was to have been turned out by the Neville Island ordnance plant. The Navy Department in May, 1918, expressed willingness to turn over to the Army certain 14-inch guns, 50 calibers, then under construction, of which it was estimated that thirty would be completed by March, 1919.

It was decided to place some of these 14-inch guns on American sliding railway mounts, and sixteen such mounts were ordered from the Baldwin Locomotive Works, deliveries to begin February 1, 1919. The sixteen units were to be delivered before April, 1919, but the signing of the armistice suspended work on the contracts, for the mounts had been designed for use in France. The contract was canceled in March, 1919.

THE NAVY'S RAILWAY BATTERIES

It was, however, in mounting 14-inch naval guns for field service that the United States scored a success in France which

is likely to be remembered long after the details of our munitions program are forgotten and which probably will live in interest with the story of the *Monitor* and that of the operation of the railway batteries in the Civil War. This exploit was not a war department affair at all, but was the single-handed achievement of the Navy, to which this seems to be a fitting place to pay tribute.

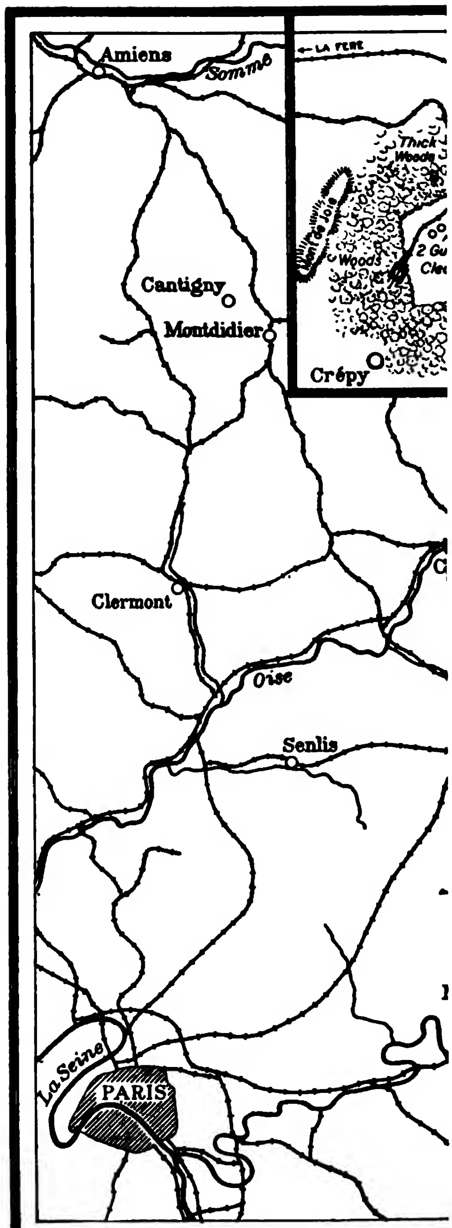
On March 23, 1918, a little after 7 o'clock in the morning (the great and final German drive having started two days earlier), the inhabitants of Paris living near the Quai de Seine were startled, and some of them were killed and injured, by a mysterious explosion. Scarcely had the military authorities of the city been apprised of this occurrence when there was another explosion, equally inexplicable, but in another section of the city; and all day long, at intervals approximately twenty minutes in duration, these explosions recurred. An investigation by the French military authorities soon developed the fact that Paris was under bombardment by a German gun of novel construction. The air forces located the long-range gun in the Gobain forest, at Laon, approximately seventy miles away from the city!

The whole civilized world buzzed with excitement at this feat, admiration for the mechanical exploit disputing with condemnation of the ruthlessness which for the sake of a mere demonstration of frightfulness and without hope of military benefit could shell the helpless civilians of a theoretical fortress. The intermittent shelling of Paris by Big Bertha, as the Allies promptly named the mysterious gun in honor of the heiress of the Krupps, continued as long as the Germans continued to advance; but the day was to come when the enemy was to be treated to a like surprise on his side. That day was September 6, 1918. Tergnier was an important railroad junction within the German lines between Laon and Amiens. The town was being hard pressed by the Allies, but it still lay comfortably back out of range of the biggest field guns which the Allies had produced during the war. The German troops were busily switching cars in the yards at Tergnier when all

unheralded came a shell into their midst, blowing out a crater into which they could have tumbled a church. The enemy, without debate, began at once to evacuate Tergnier. The shell had come from the first of the American navy 14-inch guns to get into action, which thus won its first engagement with a single shot.

The American navy guns were the heaviest weapons used in the field against the Germans during the war, and on the German side are only to be compared with the Big Bertha which shelled Paris. Yet this comparison is most interesting, affording a contrast of national psychology as well as of *matériel*. The German gun had a maximum range of 121,000 yards against a maximum of 45,000 yards for the American gun, and the German shell sped on its mission with a muzzle velocity of 4,760 feet per second against a muzzle velocity of 2,800 feet per second for the American gun. But here the favorable comparison ends for the German weapon. The recoil force of the American gun was more than six times as heavy as that of the German gun, the American gun mount having to brake a firing load of 800,000 pounds, as compared with the firing load of 127,500 pounds exerted by Big Bertha. The German shell weighed only 204 pounds. The American naval gun fired a projectile weighing 1,400 pounds and deposited eighty-eight pounds of high explosive at the objective, sufficient to gouge out a crater seventy feet in diameter. The lighter German shell could indeed do considerable damage to structures in a city, but it carried with it no such annihilation as did the American shell. In other words, the German gun was a demonstration, a stunt pure and simple;* whereas the American naval batteries were put in the field for business, the business of winning a war. Big Bertha made no contributions along this line. She could kill a few hundred helpless civilians, but the American guns annoyed and upset some of

* In fairness it should be stated that the German High Command probably expected the bombardment to start a general exodus from Paris, thus loading the railroads with civilian travel and interfering to that extent with military movements.



Drawn by Albert Hoit Bumstead

THE SHI

Larger map shows location of German lc
to Paris. Inset shows emplacements (A,]

the enemy's field operations as no other artillery had been able to do.

The German long-range guns were mounted on railway cars for transportation and afterwards mounted on turntable emplacements. It took two weeks to build one of these emplacements. The American gun could fire from the rails within ten minutes after arriving at any position—another element of practical superiority.

Several of the belligerents were using railway artillery when we entered the war. Germany, England, and France had all taken naval guns and mounted them for operation in the field by naval crews. The German railway artillery outranged that of the French and British. Thus there was precedent for the American Navy's Bureau of Ordnance when in November, 1917, it decided to take a number of 14-inch guns and mount them on railway trucks for service in France. These guns were 50 calibers in length, nearly sixty feet. The guns were ready at hand, held in reserve; and, since the war had had the effect of stopping battleship construction in favor of the construction of destroyers and other small craft for hunting submarines, there was little likelihood of the weapons being needed at sea during the war.

On November 26, 1917, the Chief of Naval Operations authorized the plan. Less than thirty days later the designers at the Naval Gun Factory in Washington had turned out complete construction plans for the equipment. Each battery was to consist of a locomotive, gun car, two ammunition cars, three construction cars, one workshop car, one fuel car, three berth cars, one kitchen car, and one headquarters car—a total of thirteen cars and one locomotive to the battery train. Five such batteries were authorized. In addition, there was provided a staff train of seven cars and a locomotive.

The gun car, the most important unit, weighed about 535,000 pounds, or considerably more than the heaviest of locomotives. This weight was distributed over the track by twenty-four car wheels, one truck of twelve wheels under each end of the gun car. The principal construction feature of the

car consisted of two long main girders, each seventy-two feet long, tied together to form a single girder unit with a center well in which the gun was mounted.

The mount was designed to be used in two ways in the field. For ranges up to 23,000 yards, requiring angles of gun elevation up to 15 degrees, the gun could be fired from the rails. The recoil was absorbed by a hydraulic brake plus the retrograde movement of the gun car with its wheel brakes set, the car moving backward a distance of twenty-five feet when the gun was fired at the elevation of 15 degrees. If greater ranges were desired, making it necessary to fire the gun at higher angles (its extreme angle and range being 43 degrees and 45,000 yards), it was necessary to mount the gun on a special emplacement. This emplacement could be built in twenty hours. The battery train carried tools and materials for the construction of such emplacements. The emplacement was so constructed that by means of jacks the gun and its mount could be quickly and easily let down upon it from the gun car.

There were many ingenious features incorporated in this design, one of them being the loading device. The 1,400-pound shell came to the gun car from the ammunition car conveyed by an overhead monorail. At the gun car the shell was placed on a car which ran up and down an inclined I beam leading to the gun breech. The crew grasped the handles of the shell car and ran the length of the cab with it. At the end of the I beam the shell car was stopped suddenly by hydraulic buffers. Thereafter the momentum of the shell carried it on through the powder chamber of the gun and forced it into the rifling.

The gun car was sheathed in quarter-inch armor plate, as were the ammunition cars. These latter were standard steel-frame box cars of 60,000 pounds' capacity. Each ammunition car could hold twenty-five shell and twenty-five powder charges on its racks. One of the construction cars in each battery mounted a 10-ton crane. The berthing cars were box cars fitted with folding berths. One of the cars of the staff train was a traveling machine shop equipped with motor-driven tools.

Bids for the construction of this equipment were opened on

February 13, 1918. The construction of the five gun cars and locomotives went to the Baldwin Locomotive Works, the vice-president of which, Mr. S. M. Vauclain, was with the War Industries Board. Mr. Vauclain became an enthusiast for the 14-inch railway gun project, and it was largely due to him that the batteries were manufactured in time enough to be operated in France. The Baldwin Works agreed to deliver the locomotives and gun cars about June 15. To the Standard Steel Car Company went the contract for the construction of the other cars—seventy-two of them. This concern promised complete delivery in from 100 to 120 days.

The whole job was put through in an astonishingly brief time. The first gun mount was complete and ready for firing on April 28, and all five were delivered by May 25, three weeks ahead of schedule. The Standard Steel Car Company produced all the other rolling stock by June 1, and this in spite of a windstorm and fire that nearly destroyed one of the shops in which the cars were being built. The locomotives, too, were produced on time.

The next step was to ship the parts to France and assemble the equipment there. The original plan had been to operate these guns with the British Army in defense of the Channel ports. Conditions in the spring of 1918 were such, however, that the British were unable to designate any of their ports in France which they were sure of holding until the material could arrive. The Navy therefore offered the batteries to General Pershing, who promptly accepted them and designated St. Nazaire as the port of debarkation and place of assembly for them.

One difficulty after another then arose to impede the project. The first ship assigned to carry the material to France was so badly battered by a storm on her trip from France to Philadelphia, where the equipment was collected, that she had to go into drydock for repairs. The second ship so assigned was sunk by a German submarine off the American coast. Finally the S. S. *Newport News* took on the first load of material at Philadelphia and sailed for France on June 29.

In France, more troubles. The bluejackets who were to erect and operate the batteries had been sent to France early, arriving at St. Nazaire on June 9, wearing overseas caps and a khaki uniform much like that of the Army. The first job was to put up some barracks. Wood being scarce, the gobs built their shore quarters out of packing-case material in which American locomotives had come crated to St. Nazaire. That took a week. Then the battery men built tracks on which to assemble their cars, borrowed a stationary boiler and a pump with which to supply air to their riveters, installed them, mended the holes in a leaky air pipe line, and then had gone as far as they could in preparation for the task ahead.

The arrival of the materials was still several weeks distant. And did these sailors thereupon proceed to enjoy their leisure and the section of France available for their excursions? They did not. St. Nazaire was the port which received and assembled the military railroad materials shipped from the United States. There was a roundhouse there, extensive railway yards, and dozens of erecting tracks, with the 19th Engineers, U. S. A., in charge. The restless gobs therefore pitched in to help the Army clear away a congestion of work, running switch engines, assisting in the roundhouse, repairing tracks, and so on, for which coöperation they received their reward later. Without a locomotive crane the work of erecting the batteries would have been toilsome indeed. There were just four such cranes available at St. Nazaire, and the Army itself had need of every one of them; but nevertheless when the *Newport News* arrived in St. Nazaire on July 8, the 19th Engineers consented to lend one of their locomotive cranes to the batteries.

The railway battery material arrived in three shiploads as a huge and indiscriminate collection of steel plates, beams, girders, trusses, wheel trucks, and so on, not forgetting the five great gun tubes.. Imagine trying to put together five gun cars, five locomotives, and some seventy railway cars of miscellaneous sorts out of such a mass of material without a blue print or a scrap of printed directions! Yet that is just what had to be done. The blue prints were sent from the United States

by special mail in ample time to reach St. Nazaire ahead of the material; but, whether the ship on which they traveled was torpedoed, at any rate they never reached their destination. The battery commander sent for another set, but before they reached France the assembling job was about complete.

When the erectors broke open the first box marked "rivets" it was found to contain stove bolts. A hasty investigation showed that all the similar boxes held stove bolts instead of rivets. Thereupon ensued a search of a large part of industrial France to secure rivets, thousands and thousands of them, for there was not a car in the whole assemblage that did not require at least 500 rivets to be driven. And when the French rivets came it was discovered that their dimensions were all according to metric-system measurements, whereas the rivet holes in the American plates had English dimensions. Therefore none of the rivets fitted; but the sailors used them nevertheless, sometimes heating and hammering and drawing them to make them fit.

None of these embarrassments, however, delayed the work. The fixed working hours for the erecting gangs were from 7:30 a.m. to noon and from 1:00 to 5:15 p.m., but the men refused to quit when the whistle blew. The long summer evenings in France gave light enough to see until almost ten o'clock at night, and the gobs stuck to it, night after night, until it was too dark to do any more work. The result was that the first battery was ready to move to the front on August 11, and all five were ready for action on September 16.

This is perhaps not the place to tell about the operation of the batteries at the front, but enough may be said to show their extraordinary value. The French prepared to give the batteries elaborate proving tests at their ground at Nuisement, but when Battery No. 1 had planted its first four shell within a stone's throw of a target eighteen miles away, the French general called off the test and sent the battery immediately to Soissons to bombard the railroad yards at Laon.

It was during the final drive of the Americans and French that the batteries were able to render greatest service. The most important supply line behind the German front was the rail-

road running northwest on a straight line from Metz to Sedan, paralleling the trenches and making it easy for the Germans to shift troops from spot to spot. For four years this track had lain safely out of range of the Allies' biggest guns, and during these four years the Germans had greatly improved the road and brought it to a high state of efficiency. The alternative line was a right angle, one leg leading north to Luxemburg and the other thence west to Sedan—50 per cent farther and poor track. For the strategic importance of the Metz-Sedan line, it is enough to say that when Pershing cut it at Sedan the war was over.

When three of the American naval batteries opened up on this railroad from points near Verdun the Metz-Sedan railroad was no longer immune from shell fire. The Germans furiously resented the innovation and concentrated efforts to put the guns out of action, shelling the positions from the ground and bombing them from the air. More than once the armor sheathing saved the guns and ammunition cars from serious injury. All three guns maintained their bombardment to the end, Battery No. 4 firing a shell at 10:57:30 o'clock on the morning of November 11. Within a few days thereafter the full extent of the damage done by this monster artillery was discovered. Here and there the tracks had been cut for distances as long as seventy feet. For days at a time the railroad service had been interrupted, forcing the enemy to use the roundabout Luxemburg route. The entire lower Montmedy freight yards had been burned, and it was reported also that a troop train in motion, loaded with German soldiers, had been hit and demolished.

After the proving-ground test of the first railway 14-inch gun (on April 30, 1918) the Ordnance Department of the Army asked the Navy to provide for the Army three such gun cars, together with two ammunition cars for each mount. These three units the Baldwin Locomotive Works delivered by July 18. The Army then asked for three more, and the Baldwins built them in less than sixty days. The naval batteries in France were turned over to the Army after the armi-

Photo by Howard E. Coffin

EMPLACEMENT OF GERMAN LONG-RANGE GUN

Photo from Bureau of Ordnance, U. S. N.

U. S. NAVAL BATTERY NO. 1 SPEAKS

Photo from Bureau of Ordnance, U. S. N.

HAVOC WROUGHT BY U. S. NAVAL GUN AT LAON

Photo by Signal Corps

1400-POUND PROJECTILES FIRED BY NAVAL RAILWAY GUNS

stice and brought back to the United States for service in our railway coast defenses.

The Navy recognized the chief weakness of these mounts—that they could not be fired at long ranges without being placed on prepared emplacements. Consequently, after the first five batteries began to demonstrate their usefulness in the field, the Navy Bureau of Ordnance set to work to design a railway 14-inch gun mount that could fire from the rails at angles of elevation up to 43 degrees. Manufacture of five cars of the improved type began in October at the Baldwin Locomotive Works, these to be in France ready for service by March 1, 1919. The armistice intervened before any of the units could be completed, and the order was thereupon cut down to two of the new mounts, the first of which was delivered in July, 1919. This was a huge affair, 110 feet long, weighing 305 tons, and supported on forty car wheels, yet so built that it could be drawn over our railroads at twenty-five miles an hour, a speed sufficient to take it from the Atlantic to the Pacific coast in a week. Both of the improved mounts were turned over to the Army for use in the coast defenses.

THE 16-INCH HOWITZER

WITHOUT discussing here the 12-inch howitzers, twenty feet long, which the Ordnance Department of the Army ordered produced and mounted on railway trucks, a development for use abroad in 1920, we come, finally, to the largest weapon in the railway artillery program—the 16-inch howitzer. The barrel of this mighty weapon was 26 feet, 6 inches long. The American 16-inch howitzer had been forged out and finished earlier than the date of America's entrance into the war. It was proposed to place this weapon on a railway mount and make it available for use on the western front.

The Ordnance Department completed the design for the mount on February 10, 1918. In order to turn out the unit in the shortest possible time, the project was placed with three manufacturers, each of whom was to produce different parts. The American Bridge Company received the order to build the

structural parts, the Baldwin Locomotive Works contracted for the trucks, and the Morgan Engineering Company undertook to assemble the unit and also to build the top carriage and other mechanical parts. The contractors did a speedy job in producing the mount for this howitzer.

In nearly all railway artillery of this size, it is necessary to provide bracing when the gun is set up in position for firing. The 16-inch howitzer mount was unique in that the weapon could be fired from the trucks without any track preparation whatsoever. An exhaustive test at the Aberdeen Proving Ground demonstrated that this piece of artillery ranked with the highest types of ordnance in use by any country in the world.

In the meantime, orders had been placed for sixty-one additional howitzers. The American Expeditionary Forces asked that twelve of these enormous weapons be sent overseas as soon as they could be produced, a job which would have extended over a period of months, if not years. Since none of the additional howitzers had been produced when the armistice was signed, the project of building mounts for them never got under way. The pilot howitzer and mount were not shipped abroad.

In the design of railway equipment for high-angle weapons such as howitzers, two loads must be considered by the builders in order to provide a gun car of sufficient strength to hold its freight. One of these loads, the lighter one, consists merely of the ordinary weight of the gun and its carriage upon the car wheels. The other load, the so-called firing load, consists of the weight of the unit plus the additional weight of the downthrust of the howitzer when it recoils. The firing load of the 16-inch howitzer is 748,231 pounds. The weight of 748,231 pounds must be distributed along the tracks by the numerous sets of wheels at the instant the gun is fired. The mount for the howitzer is so constructed that this load is partly taken up by the slide of the gun car along the track. In addition, the howitzer is equipped with a hydraulic recoil cylinder. Thus the unit has a double recoil system. In the tests the car trucks com-

fortably transmitted, through a series of equalizer springs, this enormous load upon an ordinary rock-ballast track, without any distortion of the track or roadbed or impairment of the working parts of the unit. After each discharge the whole huge mount moves backward along the track for a distance of twenty to thirty feet.

Each railway artillery project called for the manufacture of a great equipment of ammunition cars, fire-control cars, spare-parts cars, supply cars, and the like, a complete unit being a heavy train in itself. Such armament-train cars, together with numerous other accessories and necessary equipment, were designed by the Ordnance Department and produced for each mount. In all, 530 ammunition cars were produced up to April, 1919. Most of them were shipped abroad, but 118 were retained for use in this country. Since the overseas cars were to be used with French railway equipment, it was necessary to fit them out with French standard screw couplers, air brakes, and other appliances for connecting up with French railway cars.

The matter of traction power for these gun and armament trains near the front set a problem for the Ordnance Department to solve. It was out of the question to use steam engines near the enemy's lines, for the steam and smoke would betray the location of artillery trains at great distances. The Ordnance Department adopted a gas-electric locomotive of 400 horsepower to be used to pull railway artillery trains at the front, and was on the point of letting a contract to the General Electric Company for the manufacture of fifty of them when the armistice was signed.

NEVILLE ISLAND

It seems fitting at this point to say something about the Neville Island ordnance plant, on an island in the Ohio River near Pittsburg, which would have produced weapons of the type used with railway mounts, and would have turned them out in large numbers, had the armistice not come to put an end to this enormous project. The plant was being erected for the Government by the United States Steel Corporation without

profit to itself. The estimated cost of the finished plant was $150,000,000. Designed to supply the needs of the Army for artillery of the heaviest types, the Neville Island plant was being constructed on such a scale that it would surpass in size and capacity any of the famous gun works of Europe, including that of the Krupps. It was being equipped to handle huge ordnance undertakings, such as the monthly completion of fifteen great 14-inch guns and the production of 40,000 projectiles monthly for 14-inch and 16-inch guns. The plans of the Government contemplated the production of 14-inch guns to the number of 165 in all and their shipment to France in time to be in the field before May 1, 1920. An initial order for ninety of these weapons had been placed at the arsenal while it was being erected. Besides 14-inch guns, the plant was being equipped to turn out 16-inch and even 18-inch weapons. The immense size of the machinery necessary for such production can be understood when it is noted that an 18-inch gun weighs 510,000 pounds and a 14-inch gun 180,000 pounds. It requires from twelve to eighteen months to produce guns of this size; yet Neville Island was being developed on a scale to build hundreds of them simultaneously. The entire plant was to cover 573 acres and was to employ 20,000 workmen when in full operation.

At the signing of the armistice, work was suspended at Neville Island, and four months later the whole project was abandoned.

CHAPTER VI

MOTORIZED ARTILLERY

THE armistice put an end to one development being carried forward by the Ordnance Department which, in a few months, would have placed upon the field in Europe the greatest improvement in field artillery since the invention of the quick-firing cannon. The most advanced and scientifically equipped armies in the world possessed, in 1917, artillery which was mobile in the sense that the field guns could be moved by horses, motors, or other exterior motive agencies. We proposed to make our field artillery automobile, so that the gun itself could move about at the will of its crew, employing the power of gasoline motors.

The difficulties in the way of such a realization must be evident. America had developed powerful and efficient motor trucks; but field guns, at least the large ones, obviously could not be mounted upon these. Any gun of the larger sizes is an instrument which weighs tons upon tons. If a truck, even one with the driving power exerted upon all four wheels, were to bog down in mud or shell hole carrying a large gun, it would be unable to extricate itself.

But there had been invented in America a form of locomotion which could defy mud and the uptorn terrain of the western front. This was the tractor that laid its own track, the familiar caterpillar. It was man's closest mechanical approach to the insect traction that can climb up the side of a brick wall. The caterpillar device had already made possible the British development of the tank. With its extensive traction surface distributing its weight, the caterpillar will not sink down in soft going. It asks not for roads, but only for room to move about in. It is not to be stopped by hills, holes,

ditches, or even narrow trenches. Thus it seemed to be supremely well adapted for use on shelled ground.

Strange to say, not one of the European belligerents seemed to have attempted to adapt caterpillar traction to the self-movement of artillery, except the French. The French had developed a caterpillar field-gun mount known as the St. Chamond type, but this had been brought little past the experimental stage. Our own ordnance people, however, had been working with the idea, and in 1917 had produced experimentally the first self-propelled gun mount the world had ever seen. The St. Chamond type was not strictly self-propelled, for its power unit—its tractor, in other words—was designed to be uncoupled from the gun mount itself. Our own experimental mount, however, was self-contained. It was a sturdy vehicle with caterpillar, gasoline motor, and platform on which the gun was mounted. At first the thought was that carriages of this sort would be suitable only for the lighter guns; but it was decided to test the experimental mount exhaustively. Accordingly, the experimenters mounted a big 8-inch howitzer upon it and then maneuvered the tractor over difficult ground, firing the howitzer at angles of elevation as high as 45 degrees. (The greater the degree of elevation, of course, the greater the strain to the mount from the recoil of the weapon.) Yet the experimental mount, built as it was for a light anti-aircraft gun, withstood all the firing strains and in addition carried its heavy load over the broken ground in a manner highly satisfactory.

The experimental mount thereupon became the nucleus of an ambitious production program. The next step was to build and test three mounts designed especially for 8-inch howitzers. The first two of these came through and performed so well that the Ordnance Department did not wait for the third to receive its trials, but went ahead with orders for fifty more and also for fifty mounts of the same sort for 155-millimeter G. P. F. guns. These two mounts, as specified, were to be almost identical. Although the howitzer has a muzzle diameter almost two inches greater than that of the 155-millimeter gun,

the latter is a high-powered weapon with an even greater recoil force. Accordingly the mount for the 155 was made somewhat stronger than that for the 8-inch howitzer.

These caterpillar gun mounts were to cost the Government about $30,000 apiece, or fifteen times as much as an average-priced automobile—an indication of the size and power of the unit. The Harrisburg Manufacturing & Boiler Company of Harrisburg, Pennsylvania, undertook to turn out the 8-inch howitzer caterpillars, and the Morgan Engineering Company of Alliance, Ohio, those for the 155-millimeter guns. Both these concerns were manufacturers of heavy steel products.

At the time these orders were placed, the Ordnance Department contracted with the Standard Steel Car Company at its mill at Hammond, Indiana, to build 250 caterpillar mounts for 240-millimeter howitzers. This great weapon was the largest gun we attempted to put on a self-moving mount. In its motorization program the Ordnance Department was not rejecting the experience of the French, and in the contract with the Standard Steel Car Company it split the mounts ordered into two types, one a mount which followed closely the St. Chamond mount in its specifications, and one, a self-contained unit, designed by our own ordnance engineers. By the terms of its contract the Standard Steel Car Company was to build both sorts.

Both the American and the French mounts possessed their peculiar advantages. The St. Chamond mount, as indicated, was built in two units, one carrying the gun and electric motors and the other, which was the limber, carrying the power plant, as well as ammunition for the weapon. When the howitzer was in position the power plant unit could be run to some place of shelter near by, ready to move the weapon wherever the situation might demand. Thus a hit that disabled the howitzer need not necessarily cause its loss, since the power unit could drag it away from danger and take it to the repair shop. On the other hand, a direct hit could put both gun and power plant on the American mount out of commission, since both were carried on the single unit.

The American self-propelled mount, however, was ready to move the instant it had fired its shot. This was its marked advantage. As the war progressed, the systems, mechanical and other, for spotting artillery weapons on the field grew constantly better and more accurate. It often happened that a gun which betrayed its position by a shot met destruction within a few minutes. The self-propelled mount fires its shot with engine running. Almost before the projectile has reached its destination the caterpillar is on the move, getting out of range; and if the enemy has spotted the flash and opens fire, his shell fall harmlessly on a deserted position, the self-moving weapon meanwhile having taken up a new location.

None of the contractors got into production before the armistice. The project was large and the work of a new type. Moreover, the manufacturing program did not call for complete deliveries until the early part of 1919. The progress at the three plants in the autumn of 1918 indicated that these mounts would come through in time to be of service to the A. E. F. in the 1919 campaign. In this period, also, the Ordnance Department developed designs for two other self-propelled mounts, a 2½-ton and a 5-ton tractor, both for mounting 75-millimeter guns.

The armistice put a new face on the matter. The self-propelled mount was confessedly experimental, in the sense that it had received no actual trial in battle. Accordingly, although manufacturers of other large pieces of ordnance were permitted to go through with large portions of their contracts in order to conserve expenditures already made, the orders for caterpillar mounts, relatively small though they were, were radically cut down, the amended program calling for only enough mounts of each type to provide *matériel* for further experimental work in the field.

NAVY CATERPILLAR MOUNTS

The Navy, too, was an innovator in the mounting of field guns upon caterpillars. It placed twenty 7-inch battleship rifles upon such mounts for service in the field. These mounts

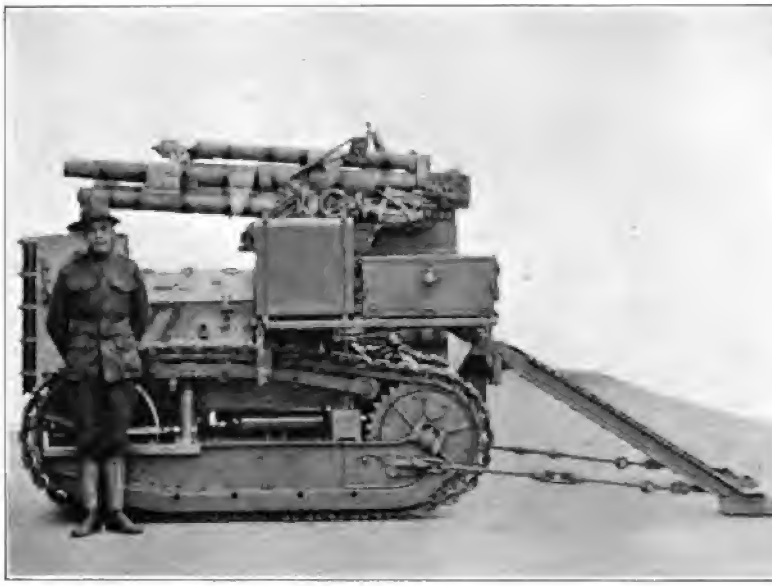


Photo from Ordnance Department

3-INCH GUN ON SELF-PROPELLED MOUNT

Photo from Ordnance Department

8-INCH HOWITZER CLIMBING RAILROAD EMBANKMENT

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Photo from Bureau of Ordnance, U. S. N.

THE NAVY'S CATERPILLAR MOUNT

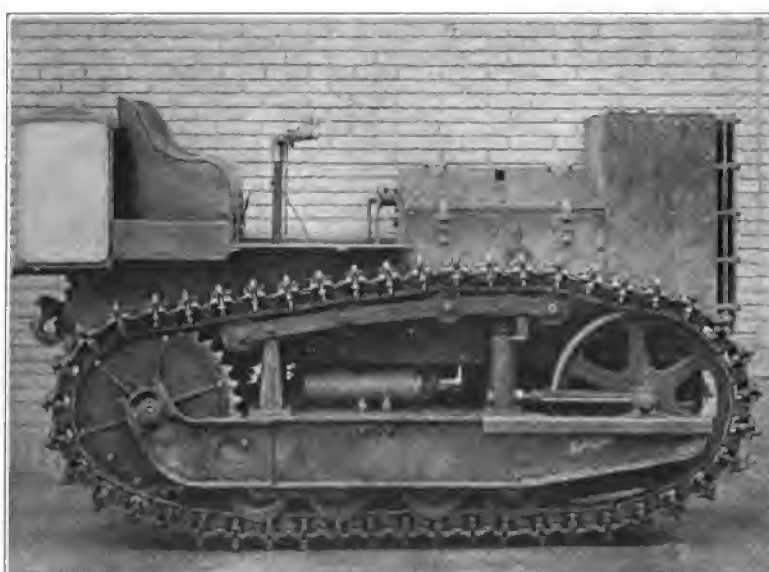


Photo from Ordnance Department

2½-TON ARTILLERY TRACTOR

were not self-propelling, but they were notable in other ways, and particularly for the reason that no other nation on earth had ever attempted to give field mobility to guns as heavy and as hard hitting as these. They represented a distinct advance in field artillery practice. The project of mounting these weapons was a highly successful one, and several of the guns were ready in plenty of time to have crossed the ocean and gone into action. The transport shortage at sea, however, kept on this side of the water the guns and the battery of marines specially organized and trained to use the pieces in the field.

A nation at war must adapt itself to conditions. The 7-inch navy field-gun project came about as a sort of by-product of one of these quick adaptations. All of the available cruisers in the American Navy in 1918 were not numerous enough to escort all the convoys of troopships and cargo transports needing protection, and it became necessary for the Navy to take several battleships of the *Connecticut* class and assign them to convoy duty. Ships thus continually running the war zone had to be as nearly torpedo-proof as they could be made. Each ship of the *Connecticut* class was equipped with a secondary battery of 7-inch guns mounted between decks, a useful auxiliary in any engagement with surface vessels, but a menace when the antagonist was a submarine. The torpedoing of a ship was usually followed immediately by a heavy list, which moderated after the water-tight bulkheads began to hold up the vessel. The 7-inch batteries between decks on the battleships selected for convoying necessitated wide openings in the vessels' sides down near the water, making it likely that any one of them if torpedoed would at the first list take in enough water through these ports to capsize her. Accordingly the 7-inch guns were removed, and the ports were sealed permanently.

Thus was made available a considerable number of big, powerful guns for which there seemed to be no war use. They were too heavy to be mounted on the decks of armed merchantmen. The Army took a dozen of these guns and mounted them on railway cars for coastal protection, as described in the pre-

ceding chapter. The Navy was starting to do likewise with a few of them when word came from France that if some of these guns were placed on mobile field mounts, the A. E. F. would have something that would make the other belligerents on both sides take notice.

Yet, looked at in any way, it was a staggering project. The gun was twenty-six feet long and weighed fourteen tons. Its cradle, recoil device, and other elements of the mount would at least double that weight. The gun when fired exerted a recoil pressure of 195,000 pounds. The shipboard mount allowed for an elevation of only 15 degrees, giving the gun a range of 14,000 yards. On the field mount it was proposed to allow for an elevation of 40 degrees, which would make the range in the neighborhood of 24,000 yards, or over thirteen miles. The problem was to design a mount capable of withstanding these weights and pressures which still could move over difficult ground. Moreover, although the project was not started until the spring of 1918, the Navy was asked to produce these mounts, not in 1919 or 1920, but before the close of 1918. It was proposed to make such mounts for twenty guns.

The Navy Ordnance Bureau first thought of a wheeled mount, but a brief calculation showed that wheels would not be practicable. Even with 6-foot wheels with wide tires, the gun and mount would put a pressure of eighty-eight pounds upon each square inch of the tires in contact with the ground. The path of such a weight over an improved road would be marked by a crushed and broken roadbed, and if the piece left the road and got into soft ground, it would soon become mired. The caterpillar form of traction was the solution. Mounted on a caterpillar with a ground contact area of twenty-eight square feet, the bearing pressure would be only eighteen pounds per square inch, or about half that exerted by a horse's hoof.

Caterpillar traction, therefore, was adopted. For motive power to drag the mount the Bureau adopted the 120-horsepower Holt caterpillar tractor, the largest gasoline tractor built in the United States. A special lengthened recoil set—

hydraulic and pneumatic in combination—was designed to reduce the recoil pressure upon the carriage. Practically every other feature of the mount had to be designed anew—scarcely any of the parts of the ship mount could be used. Starting March 15, the designers turned out the completed drawings on May 25. On June 18 the Baldwin Locomotive Works accepted a contract to turn out twenty mounts by October 18. Mr. S. M. Vauclain, the vice-president of the company, took a special interest in the contract, with the result that the first two mounts complete were shipped from the factory on September 26, just one hundred days from the date of the contract. The other eighteen mounts followed at intervals of two and three days each.

The first guns were tested at Indian Head, Maryland, on the Potomac, by a regiment of U. S. Marines assembled for the purpose. The tractors dragged the heavy guns up hill and down, along hillsides and over newly plowed ground. The guns could go anywhere the tractors could. The range was found to be 24,000 yards. The mounts proved themselves able to keep the guns in battery during continued firing.

Army ordnance officers watched these tests, and as a result the Ordnance Department of the Army at once asked the Navy to construct thirty-six such mounts for the Army. This contract also went to the Baldwins. The armistice found the project so well advanced that it was possible to cancel the orders for only eighteen of these army mounts.

The present day therefore finds the United States in possession of thirty-eight 7-inch mobile field guns,—twenty with the Marine Corps and eighteen with the Army,—the highest powered weapons ever given mobile field mounting by any nation. At a range of 14,000 yards the shell of one of these guns can penetrate several feet of concrete or earthworks, exploding a bursting charge of twenty-four pounds of trinitrotoluol. The guns can be hauled over open country and are superior to any field gun in the world, so far as is known in this country.

CATERPILLAR TRACTORS

Although the development of the self-propelled mount cut no figure in the ordnance production statistics of 1918, in another respect, by taking an intermediate step between the artillery which is drawn by horses and that in which the guns are completely self-contained, the Ordnance Department made great progress. This was in the production of caterpillar tractors for dragging guns, limbers, and caissons, in substitution for the teams of artillery horses which have been so spirited a feature of battle scenes of the past. Perhaps the chief lesson taught the Army in the campaign of the Punitive Expedition into Mexico was the need for the motorization of our artillery and supply wagons. Ordnance officers who witnessed or read reports of the toil and exhaustion of the horses which hauled heavy guns over the northern Mexican desert began experimenting at the Rock Island Arsenal; and when we declared war against Germany they had made considerable progress with special designs for caterpillar tractors.

Machines of five sizes were required, with capacities respectively of 2½, 5, 10, 15, and 20 tons. The three smaller sizes had to be designed especially for the Army and afterwards put in production, but the Ordnance Department found commercial 15-ton and 20-ton tractor engines of the combination caterpillar and wheeled type which, after some slight changes in design, would serve our purposes.

Nearly 25,000 caterpillar tractors of these five types were ordered, six manufacturers participating in the contracts—the Holt Manufacturing Company, of Peoria, Illinois (holder of the patents on the caterpillar traction device), the Chandler Motor Car Company, of Cleveland, Ohio, the Reo Motor Car Company, of Lansing, Michigan, the Maxwell Motor Car Company and the Federal Motor Truck Company, both of Detroit, Michigan, and the Interstate Motor Company, of Indianapolis, Indiana. The smaller specially designed tractors were ordered the more numerously, the order for 5-ton tractors comprising in number nearly half the entire project. Nearly 2,500 artillery tractors came from the factories before the

armistice, and considerably more than half this output crossed to France, in spite of the limitations of ship space.

In line with the development of the self-propelled gun mounts came the designing of special caterpillar caissons and ammunition carriers for use in the rough country where shelling had destroyed the roads. Caterpillar fuel carriers for the motors of the self-propelled artillery units were also required. The production of two sizes of these vehicles was about to start when the armistice halted the enterprise.

TRUCKS

In its field supply service the Army needed automotive vehicles of three distinct types. As we have seen, for use on the shelled terrain of the actual front the Ordnance Department adopted the caterpillar tractor, which could go anywhere that horses could go and could even negotiate country too rough for the pliant animal power. Behind that was an area which was not under daily fire, but in which the activities of war had cut and hacked the roads and made them practically impassable by ordinary motor vehicles. Still farther back the roads were in good repair and suitable for traffic of all sorts.

The caterpillar, of course, could travel almost equally well in any of the three areas; but the disadvantage of the caterpillar is its snail-like speed. The Army therefore adopted vehicles that could make the best of any terrain—caterpillars for the battle front, swift, powerful motor trucks of the common commercial types for the good roads of the back zones, and for the intermediate area, the ground in which the roads were difficult, the four-wheel-drive truck, usually called by its initials, the f. w. d. truck.

As the name indicates, the f. w. d. truck is one in which the engine is coupled up to all four wheels and exerts driving power upon all of them. The result is increased traction efficiency. The commercial truck commonly seen on city streets or country roads is driven by the rear wheels only. If these become mired, the truck is helpless. The f. w. d. truck, with all its wheels taking purchase on the ground, can scramble

with surprising agility out of situations that would stall a truck of less traction power. The Ordnance Department adopted this truck as its chief supply vehicle and became a heavy purchaser of it.* The armistice found the Department designing an f. w. d. truck which was standardized.

Five of every six ordnance trucks were used for hauling ammunition. For this purpose special bodies were designed and built. A few were equipped with special bodies for carrying machine guns and trench mortars. Practically all the rest were designed for use as field repair shops at which emergency repairs to the artillery could be made and other field ordnance could be reconditioned.

The ordnance truck program was a large one. It required much work in designing, especially in designing the specialized truck bodies. Yet the production of ordnance trucks and bodies was great, handled as it was by the extensive motor-truck manufacturing industry of the United States. Over 9,000 ordnance trucks were sent to the A. E. F. before the armistice.

The Ordnance Department also supplied staff observation cars and reconnaissance cars to the A. E. F. These, although they had the appearance of passenger automobiles, were in reality trucks. The observation car consisted of a touring car body mounted on a 1-ton White truck chassis. The reconnaissance car body was mounted on a Commerce truck chassis. Most of these special cars were produced ahead of the armistice, and over 500 of the 2,250 ordered were shipped to France.

In all, some 30,000 f. w. d. ordnance trucks were ordered, and nearly half of them were delivered to the Army before the armistice. The plan followed by the Ordnance Department was to order chassis only from the truck builders and procure the specially designed bodies from concerns equipped to build them. The companies named below were the ordnance truck builders:

* The ordnance trucks are not to be confused with the standardized truck of the Quartermaster Service, about which something is to be said later on.

Nash Motors Co., Kenosha, Wisconsin.
Four-Wheel-Drive Auto Company, Clintonville, Wisconsin.
Mitchell Motor Car Company, Racine, Wisconsin.
Premier Motor Corporation, Indianapolis, Indiana.
Kissel Motor Car Company, Hartford, Wisconsin.
Hudson Motor Car Company, Detroit, Michigan.
National Motor Car Company, Indianapolis, Indiana.
Paige Motor Car Company, Detroit, Michigan.
Commerce Motor Car Corporation, Detroit, Michigan.
White Company, Cleveland, Ohio.
Dodge Motor Car Company, Detroit, Michigan.

The builders of ordnance truck bodies were as follows:

American Car & Foundry Company, Berwick, Pennsylvania.
J. G. Brill Co., Philadelphia, Pennsylvania.
Hale & Kilburn Corporation, Philadelphia, Pennsylvania.
Dunbar Manufacturing Company, Chicago, Illinois.
Pullman Company, Pullman, Illinois.
Kuhlman Car Company, Cleveland, Ohio.
C. R. Wilson Body Company, Detroit, Michigan.
Insley Manufacturing Company, Indianapolis, Indiana.
Lang Body Company, Cleveland, Ohio.
Heil Company, Milwaukee, Wisconsin.
Variety Manufacturing Company, Indianapolis, Indiana.
J. E. Bolles Iron & Wire Company, Detroit, Michigan.

TRAILERS

One novelty in the ordnance motorization program was the development of the trailer. The trailer was in reality a four-wheeled freight car of the highways, used coupled to a truck which served as its locomotive for swift transport of field guns and other heavy ordnance. Its principal use was in carrying anti-aircraft artillery, quick concentrations of such weapons being required by the conditions of aërial warfare. Although the 75-millimeter gun rolls on its own wheels, its carriage is at best a lumbering vehicle. The designers produced a 3-ton trailer on which the gun and its limber and caissons could ride when it needed rapid transportation. One trailer would hold the gun carriage and limber, and another two caissons.

The chassis of a 4-ton trailer was used as the mounting for a mobile repair shop body.

Not the least interesting feature of the trailer program was the 10-ton trailer used for the road transportation of the 6-ton Renault tank adopted by us from the French. By the use of trailers the small tanks could be concentrated rapidly at any point along the front where a drive was to start.

The trailers built were of five types: a 1½-ton and a 3-ton trailer for the anti-aircraft guns, the 3-ton trailer for the 75-millimeter field gun, the 4-ton trailer for the mobile repair shops, and the 10-ton tank trailer. All these vehicles were produced to meet war conditions as they existed in France, and therefore they required individual study and special design, with what that implies of special machinery for the manufacturing plants. Yet the production was large, over 1,000 being delivered to the Ordnance Department before November 11, 1918. Of these, about 350 were shipped to the A. E. F. The trailer builders were Sechler & Company and the Trailmobile Company, both of Cincinnati, Ohio, and the Ohio Trailer Company and the Grant Motor Car Corporation, both of Cleveland.

The officers of the Allies were loud in their praises of American artillery motorization; particularly, they applauded our equipment of artillery repair trucks, proclaiming it the best in use in Europe. The complete motorization project was represented by 3,000 contracts placed by the Ordnance Department, involving an expenditure of $365,000,000.

Production of Ordnance Motor Vehicles

TRACTORS

Size	Quantity ordered	Quantity accepted Nov. 11, 1918	Quantity accepted Jan. 31, 1919	Floated to Nov. 11, 1918
2½-ton	5,586	10	25	2
5-ton	11,150	1,543	3,480	459
10-ton	6,623	1,421	2,014	628
15-ton	267	267	267	232
20-ton	1,165	126	154	81

TRAILERS

1½-ton anti-aircraft machine gun	2,289	150	562	126
3-inch field gun . . .	830	235	472	15
4-ton shop bodies . . .	576	101	384	12
4-ton shop chassis . .	576	260	555	..
10-ton	540	104	245	1
3-inch anti-aircraft . .	612	543	611	199

TRUCKS

F. W. D. chassis . . .	13,907	5,361	10,615	3,561
Nash chassis	16,165	7,137	12,884	5,859
Ammunition bodies . .	24,729	18,212	21,709	....
Ammunition mountings .	24,729	9,615	11,024	6,955
Artillery repair . . .	1,332	1,318	1,332	350
Artillery supply . . .	5,474	813	1,838	444
Light repair	1,012	1,012	1,012	362
Dodge chassis	1,012	1,012	1,012	436
Commerce chassis . .	1,500	1,500	1,500	24
Machine gun body, mounted on Commerce or White 1-ton chassis	1,500	486	1,306	241
1-ton supply	60	60	60	55
White chassis	2,695	1,929	2,695	575
Reconnaissance . . .	1,081	712	1,003	320
Staff observation . . .	1,175	1,164	1,175	189
Equipment repair . .	310	310	310	121
H. M. R. S. trucks . .	624	287	416	12

CHAPTER VII

SIGHTS AND FIRE-CONTROL APPARATUS

AT the threshold of the war with Germany we were confronted with the problem of providing on a large scale those instruments of precision with which modern artillerists point their weapons. As mysterious to the average man as the sextant and other instruments which help the navigator to bring his ship unerringly to port over leagues of pathless water, or as those devices with which the surveyor strikes a level through a range of mountains, are the instruments which enable the gunner to drop a heavy projectile exactly on his target without seeing it at all.

The old days of sighting a cannon point-blank at the visible enemy over the open sights on the barrel passed with the Civil War. As the power of guns increased and their ranges lengthened, artillerists began firing at objects actually below the horizon or hidden by intervening obstacles. These conditions necessarily brought in the method of mathematical aim which is known as indirect fire.

In the World War indirect firing was so perfected that, within a few seconds after an aviator or an observer in a captive balloon had definitely located an enemy battery, that battery was deluged with an avalanche of high-explosive shell and destroyed, even though the attacking gunners were several miles away and hills and forests intervened to obscure the target from view. With the aid of correlated maps in the possession of the battery gunners and the aërial observer, a mere whisper of the wireless sufficed to turn a torrent of shell precisely upon the enemy position which had just been discovered. So accurate had indirect artillery fire become that a steel wall of missiles could be laid down a few yards ahead of a body of troops advancing on a broad front, and this wall could be kept

Photo from Ordnance Department

5-TON ARTILLERY TRACTOR

Photo from Ordnance Department

20-TON ARTILLERY TRACTOR

Photo from Recording & Computing Machines Company

GRINDING LENSES AND PRISMS

Photo from Penn Toy Company

MANUFACTURING TRENCH PERISCOPES

moving steadily ahead of the soldiers at a walking pace, with few accidents due to inaccurate control of the guns firing the barrage.

The chief difference between the old and the new methods of artillery practice is the degree of precision attained. At the time of the Civil War the artillery was fired, by comparison, blindly, reliance being placed upon the weight of the fire, regardless of its accuracy and its effectiveness; but modern artillery has recognized the importance of the well-placed shot and demands instruments that must be marvels of accuracy, since a slight error in the aiming at modern ranges means a miss and the total loss of the shot. Such uncanny accuracy is made possible by the use of those instruments of precision known as fire-control apparatus. The gunner who is not equipped with proper fire-control instruments can not aim correctly and is placed at a serious disadvantage in the presence of the enemy. These instruments must not only be as exact as a chronometer, but they must also be sufficiently rugged to withstand the concussion of close artillery fire.

The equipment classified under the designation "Sights and fire-control apparatus" comprises all devices to direct the fire of offensive weapons and to observe the effect of this fire in order to place it on the target. Included in this list are instruments akin to those used in surveying, which serve to locate the relative position of the target on the field of battle and to determine its range. For this purpose the artillery officer uses aiming circles, azimuth instruments, battery commander telescopes, prismatic compasses, plotting boards, and other instruments. Telescopes and field glasses equipped with measuring scales are also employed in making observations.

Instruments of a second group are attached directly to the gun, to train it both horizontally and vertically in the directions given by the battery commander. These devices include sights of different types, elevation quadrants, clinometers, and other instruments. The intricate panoramic sight, which is used especially in firing at an unseen target, is one of the most important instruments of this group.

Still another set of instruments comprises devices such as range deflection boards, deviation boards, and wind indicators, which, together with range tables and other tables, assist the battery commander to ascertain the path of the projectile under any condition of range, altitude, air pressure, temperature, and other physical influences. When it is understood that the projectile fired by such a weapon as the German long-range gun which bombarded Paris at a distance of seventy miles mounts so high into the air that it passes into the highly rarefied layers of the air envelope surrounding the earth, and hence into entirely different conditions of air pressure, it can be realized how abstruse these range calculations are and how many factors must be taken into account. The fire-control equipment enables the artilleryman to make these computations quickly.

In addition to the above items, many auxiliary devices are needed by the artillery, notable among these being the self-luminous aiming posts and other arrangements which enable the gunners to maintain accuracy of fire at night. This whole elaborate set of instruments is supplied to the field and railway artillery and in part to trench-mortar batteries and even to machine guns, which during the later months of the war were used in indirect firing.

Still another group of pointing instruments is used by anti-aircraft guns against hostile aircraft, to ascertain their altitude, their speed, and their future location, in order that projectiles fired by the anti-aircraft guns may hit these high and rapidly moving targets. Sights are also used on the airplanes themselves to aid the pilot and the observer in the dropping of bombs and in gunfire against enemy planes or targets. Bomb sights of one improved type correct automatically for the speed and direction of the airplane. Fuse setters, which enable the gunner to time the fuse in the shell so that the projectile, moving with enormous speed, explodes at precisely the desired point, were required in large numbers.

The responsibility for the design, procurement, production, inspection, and supply of all this equipment to the American

Expeditionary Forces was lodged in the Ordnance Department. The effectiveness of the artillery on the field of battle depended directly on the fire-control equipment furnished by this bureau.

The optical industry in this country before the war had been in the hands of a few firms. Several of these were under German influence, and one firm was directly affiliated with the Carl Zeiss Works, of Jena, Germany. In all of them the workmen were largely Germans or of German origin; the kinds and designs of apparatus produced were for the most part essentially European; and the optical glass used was procured entirely abroad and chiefly from Germany. It had been easier and cheaper for manufacturers to order the glass from abroad than to develop its manufacture in this country. Educational and research institutions obtained a large part of their equipment from Germany, and they offered no special inducement to American manufacturers to provide such apparatus. Duty-free importation favored and encouraged this dependence on Germany for scientific apparatus.

When the World War began, in 1914, the European sources of supply for optical glass and optical instruments were cut off abruptly, and we were brought face to face with the problem of furnishing these items to the Army and Navy out of our own resources. Prior to 1917 only three or four private manufacturers in the United States had built fire-control apparatus in any quantity for the Government. The Bausch & Lomb Optical Company, Rochester, New York, had made range finders and field glasses for the artillery and infantry, and gun sights, range finders, and spyglasses and field glasses for the Navy; the Keuffel & Esser Company, Hoboken, New Jersey, had produced some fire-control equipment for the Navy; the Warner & Swasey Company, Cleveland, Ohio, with J. A. Brashear, Pittsburg, Pennsylvania, had furnished depression-position finders, azimuth instruments, and telescopic musket sights to the Army. The only other source of supply in this country had been the Frankford Arsenal. The largest order for fire-control equipment which our Army had ever placed in a single year before 1917 amounted to $1,202,000. The total orders for such

instruments placed by theOrdnance Department alone during the nineteen months of war exceeded $50,000,000, and the total orders for fire-control apparatus placed by the Army and Navy exceeded $100,000,000.

To meet the situation, existing facilities had to be increased, new facilities developed, and similar industries converted to the production of fire-control material. Quantity production had to be secured through the assembling of standardized parts of instruments which before that day had either never been built in this country or built in only a small, experimental way. A large part of the work had of necessity to be done by machines operated by relatively unskilled labor. The manufacturing tolerances had to be nicely adjusted among the different parts of each instrument, so that wherever less precise work would answer the purpose, the production methods could be arranged accordingly. Only by a careful coördination of design, factory operations, and field performance could quantity production of the desired quality be obtained in a short time. Speed of production meant everything if our troops in the field were to be equipped with the necessary fire-control apparatus and thus be enabled to meet the enemy on even approximately equal terms.

To accomplish this object, a competent *personnel* within the Army had to be organized and developed; the army requirements had to be carefully scrutinized and coördinated with reference to their relative urgency; manufacturers had to be encouraged to undertake new tasks and to be impressed with the necessity for whole-hearted coöperation and with the importance of their part in the war; raw materials had to be secured and their transportation assured. These and other factors were faced and overcome. Although American fire-control instruments did not reach the front in as large numbers as were wanted, great quantities were got under way, and we attained in the manufacturing program a basic stage of progress which would have cared for all our needs in the spring and summer of 1919.

Incidentally the enterprise developed in this country a

manufacturing capacity for precision optical and instrument work, which rendered us potentially independent of foreign markets. At the armistice there existed in this country a trained *personnel* and adequate organization for the production of optical instruments of precision greatly in excess of the needs of the country. One of the problems of the demobilization was the diversion of this development, brought about by war-time conditions, into channels of peace-time activity.

In April, 1917, the most serious problem in the situation was the manufacture of optical glass. Before 1914 practically all the optical glass used in the United States had been imported from abroad. Our manufacturers, following the line of least resistance, preferred to procure certain commodities, such as optical glass, chemical dyes, and other materials difficult to produce, direct from Europe instead of undertaking their manufacture here. The war stopped this source of supply abruptly, and in 1915 experiments in the making of optical glass were under way at five different plants—the Bausch & Lomb Optical Company, at Rochester, New York; the Bureau of Standards, at Pittsburg, Pennsylvania; the Keuffel & Esser Company, at Hoboken, New Jersey; the Pittsburg Plate Glass Company, at Charleroi, Pennsylvania; and the Spencer Lens Company, at Buffalo, New York. By April, 1917, the situation had become acute; some optical glass of fair quality had been produced, but nowhere had its manufacture been placed on an assured basis. The glass-making processes were not adequately known. Without optical glass, fire-control instruments could not be produced; optical glass is a thing of high precision, and in its manufacture accurate control is required throughout the factory processes.

In this emergency the Government appealed for assistance to the Geophysical Laboratory of the Carnegie Institution of Washington. This laboratory had been engaged for many years in the study of solution—such as that of optical glass—in high temperatures, and it had a corps of scientists trained in the sort of technique which is essential to the successful production of optical glass. It was the only organization in the country

with a *personnel* competent to undertake a manufacturing problem of this intensiveness and magnitude. Accordingly, in April, 1917, a group of its scientists was placed at the Bausch & Lomb Optical Company and given virtual charge of the plant; its men were assigned to the different factory operations and made responsible for them. By November, 1917, the manufacturing processes at this plant had been mastered, and large quantities of optical glass of good quality were being produced. In December, 1917, the work was extended, men from the Geophysical Laboratory taking practical charge of the plants of the Spencer Lens Company and of the Pittsburg Plate Glass Company. The cost to the Geophysical Laboratory of solving the optical glass problem amounted to about $200,000, but the results attained surely more than justified this expenditure.

The results could not have been obtained, however, without the hearty coöperation of the manufacturers and of the Army and Navy, which assisted in the procurement and transportation of the raw materials. An ordnance officer was in charge of the Rochester party from the Geophysical Laboratory, and he was responsible for much of the pioneer development work accomplished there. It was at this plant, that of the Bausch & Lomb Optical Company, at Rochester, that the methods of manufacture were first developed and placed on a production basis. The Bureau of Standards aided in the development of a chemically and thermally resistant crucible in which to melt optical glass; also in the testing of optical glass, and especially in the testing of optical instruments. The Geological Survey aided in locating sources of raw materials, such as sand of adequate chemical purity.

By February, 1918, the supply of optical glass was assured; but the manufacture of optical instruments was so seriously behind schedule that the Military Optical Glass and Instrument Section was formed in the War Industries Board to take charge of the optical instrument industry of the country. Through the efforts of its chief, Mr. George E. Chatillon, of New York, the entire industry was coördinated. By September,

1918, the production of fire-control instruments in sufficient quantities to meet the requirements of both Army and Navy during 1919 was believed to be assured.

To the accomplishment of this result the Ordnance Department contributed most effectively. The information and long experience of Frankford Arsenal in instrument manufacture and in the work of optics of precision were placed at the service of contractors; trained officers of the Ordnance Department were stationed at the different factories; and in many factories these officers rendered valuable aid in devising and developing proper and adequate factory operations, in establishing production on a satisfactory basis, in securing the proper inflow of raw materials, in devising testing fixtures, in establishing proper manufacturing tolerances, and in testing the performance of the assembled instruments. Schools for operatives in precision optics were established at Frankford Arsenal, Philadelphia, Pennsylvania, at Rochester, New York, and at Mount Wilson Observatory, Pasadena, California. To many contractors financial aid had to be extended. The fire-control program required, in short, all the available talent and resources of the country, if it were to be carried to a successful finish.

The general procedure adopted by the Ordnance Department was to assign the more difficult instruments to manufacturers who had had experience in cognate problems. To others, who had produced articles related only in a distant way to fire-control instruments, less intricate types of instruments were awarded. In certain instances the optical elements were produced by one firm and the mechanical parts by another, the final assembly of the instrument being then accomplished by the latter.

Because our Army had adopted a number of French guns for reproduction here, it became necessary to build sights for these weapons according to the French designs. This necessity gave us much trouble, not only because of the delay in securing samples and drawings from France, but also because of the

difficulties in producing articles from these French drawings by American methods and with American workmen.

The most intricate of these French sights was the Schneider quadrant sight. It was used with the French 155-millimeter gun, the 155-millimeter howitzer, and the 240-millimeter howitzer. The structure of this sight was highly complicated, and extreme accuracy was required at every stage of production. These sights were put into production by the Emerson Engineering Company of Philadelphia, the Raymond Engineering Company of New York, and by Slocum, Avram & Slocum of New York. The design of this sight was received from France early in 1918. It was the 1st of November—ten days before the armistice was signed—when the first Schneider sight was delivered to the Army; yet at all times the progress made had been as rapid as could be expected. A total of 7,000 Schneider quadrant sights was ordered, which meant a year's work for 1,000 men. Of this order, 3,500 sights were to be manufactured by Schneider et Cie. in France and the rest by the three firms in this country. On November 11 the American factories had delivered seventy-four sights.

The amount of labor involved in the Schneider quadrant sights is shown by the fact that, whereas the raw material cost about $25, the finished sight was worth about $600. In order to expedite production the Government extended financial assistance to some of the factories, to aid in the procurement and installation of additional equipment. On November 11 the number of these sights completed was short of requirements for installation on completed carriages by about 400, but the rate of progress which had been attained in production would have overtaken the output of gun carriages by January 1, 1919.

Another difficult task was the construction of telescopic sights for the French 37-millimeter guns, the "infantry cannon" which we adopted for reproduction in this country. Here again we encountered the same difficulty, that of adapting French plans to our methods. The original contract was placed with a firm which had had no experience with optical instru-

ments of precision, because no other company was then available for the work. By May, 1918, this concern had produced only a few sights. The contract was then taken from it and placed with a subcontractor, the Central Scientific Company of Chicago, which had been building mechanical parts for the sights. In this plant the complete force had to be educated in the art before any production could begin. When the armistice was signed the factories had produced 826 guns, but only 142 telescopic sights had been completed. The rate of production of these sights by the Central Scientific Company was such, however, that the shortage would have ceased to exist shortly after January 1, 1919.

The French design for the telescopic sight for the 37-millimeter gun used on the tanks was also adopted by the Army. Here again difficulty was experienced in manufacture, but excellent progress was made, especially by one firm,—Burke & James of Chicago, Illinois,—and the output in adequate quantities was assured for 1919. The French collimator sight for the 75-millimeter gun presented difficulties to the manufacturer, especially in the optical parts. These were, however, overcome by the Globe Optical Company, which furnished the optics to the Electric Auto-Lite Corporation and to the Standard Thermometer Company of Boston. By the signing of the armistice the production of these sights was progressing well.

Periscopes from twenty inches to nearly twenty feet in length were produced in quantity. These periscopes enabled the men in the front-line trenches to look over the top with comparative safety. The long periscopes were used in deep-shelter trenches and bomb proofs. The production of the short-base periscopes and also of the battery commander periscopes by the Wollensak Optical Company, Rochester, New York, and of the 3-meter and 6-meter periscope by the Andrew J. Lloyd Company of Boston, Massachusetts, was progressing at such a rate that the needs of the Army for 1919 would have been met on time.

At the outbreak of the war the policy followed by the Ordnance Department was to place orders for standard fire-control

apparatus, such as range finders of different base lengths, battery commander telescopes, aiming circles, panoramic sights, musket sights, and prismatic compasses, with firms of established reputation and experience. When requests from the Army in France came for instruments of new design, new sources of manufacture had to be sought and new organizations educated in the methods of precision optics. Such a procedure necessarily caused delay, but it was the only course of action left. Wherever possible, part of the total contract was awarded to an experienced manufacturer, so that some minimum of production was assured.

The records show that the experienced manufacturers overcame the difficulties encountered and in general attained a rate of output which was satisfactory at the time of the signing of the armistice. For example, the Bausch & Lomb Optical Company delivered large numbers of range finders of base lengths of eighty centimeters, one meter, and fifteen feet, and battery commander telescopes; Keuffel & Esser made many prismatic compasses and a few range finders; the Spencer Lens Company produced aiming circles in quantity; the Warner & Swasey Company, with J. A. Brashear of Pittsburg, furnished large numbers of the valuable panoramic sights with which much of the artillery fire is directed. Credit is due the above organizations for the efficient manner in which they placed the manufacture of these items on a high-speed production basis. Frankford Arsenal proved to be a most reliable source of supply for battery commander telescopes, panoramic sights, azimuth instruments, 3-inch telescopes, plotting boards, and other ordnance fire-control instruments.

The manufacture of many other types of instruments was undertaken in this country. Among these, the French sitogoniometer, a device which assists the battery commander in obtaining data for the direction of fire, was successfully produced by the Martin-Copeland Company of Providence, Rhode Island; quadrant sights for the 37-millimeter gun by the Scientific Materials Company of Pittsburg; lensatic compasses and Brunton compasses were furnished by William

Ainsworth & Sons of Denver, Colorado; prismatic compasses by the Sperry Gyroscope Company of Brooklyn, New York; telescopes for sights on anti-aircraft carriages by the Kollmorgen Optical Corporation of Brooklyn; altimeters, gunners' quadrants, elevation quadrants, and aiming stakes by the J. H. Deagan Company of Chicago, Illinois; panoramic telescopes and fuse setters by the Recording & Computing Machine Company of Dayton, Ohio; battery commander telescopes by Arthur Brock of Philadelphia; and tripods for fire-control instruments by the National Cash Register Company of Dayton, Ohio. Optics for different sights were furnished by the American Optical Company of Southbridge, Massachusetts, and by the Mount Wilson Observatory of Pasadena, California. These and other organizations entered into the task and devoted their energy to the production of equipment desired by the Government.

At no time during the fighting did our artillery units have a sufficient supply of fire-control instruments. The shortage was due to the fact that we were not able to secure in Europe the amount of this equipment required to take care of our needs while our own industry was being developed. With an almost total lack of optical glass in this country, with an equal lack of factories and workmen familiar with military optical instrument-making, we were suddenly called upon to produce about two hundred different types of instruments in large quantities. These included many new designs of fire-control apparatus made necessary by new artillery developments, both among the Allies and in our own factories, by the adoption of trench warfare in place of open warfare, by the development of weapons for use against aircraft, by the extension of indirect fire-control methods to weapons which formerly had been fired by direct sighting, and by the use of railway and seacoast artillery. Though we did not solve all the difficulties in this development, we met and conquered the worst of them, and we were making such great strides in production when the war ended that all the requirements of the Army would have been met early in 1919.

CHAPTER VIII

EXPLOSIVES, PROPELLANTS, AND ARTILLERY AMMUNITION

THE Interallied Ordnance Agreement of the late fall of 1917, though it supplied the United States with French and British artillery and other heavy ordnance supplies until the developing American ordnance industry could come into production, called upon the United States to produce heavily the explosives and propellants that are of such major importance to a modern army. These commodities were needed by the armies of France and Great Britain more than any other sort of ordnance which America could supply. The result was an enormous production of propellants and explosives in the United States during the period of American belligerency. No other prime phase of the ordnance program was carried to such a stage of development.

The reader will clearly see the distinction between propellants and explosives. The propellant is the smokeless powder that sends the shell or bullet from the gun; the explosive is the bursting charge within the shell.

To realize the expansion of the American explosives industry during the war period, consider such figures as these: America in nineteen months turned out 632,504,000 pounds of propellants—the powder loaded into small-arms cartridges or packed into the big guns behind the projectiles. In those same nineteen months France produced 342,155,000 pounds of propellants and Great Britain 291,706,000 pounds. The American production was practically equal to that of England and France together.

In those nineteen months we produced 375,656,000 pounds of high explosives for loading into shell. In the same nineteen

months England produced 765,110,000 pounds of high explosives and France 702,964,000 pounds. America was below both France and England in total output, but in monthly rate of output America had reached 47,888,000 pounds, as against France's 22,802,000 pounds and England's 30,957,000 pounds. Our rate of manufacturing propellants at the end of the fighting had risen to 42,775,000 pounds, as against France's 17,311,000 and England's 12,055,000.

FIGURE 14

Production of Smokeless Powder and High Explosives: France and United States Compared with Great Britain

Average Monthly Rate, August, September, and October, 1918

Smokeless powder:	*Pounds*	*Per cent of rate for Great Britain*
Great Britain	12,055,000	100
France	17,311,000	144
United States	42,755,000	355
High explosives:		
Great Britain	30,957,000	100
France	22,802,000	74
United States	43,888,000	142

Total Production, April 6, 1917, to November 11, 1918

Smokeless powder:	*Pounds*	*Per cent of rate for Great Britain*
Great Britain	291,706,000	100
France	342,155,000	117
United States	632,504,000	217
High explosives:		
Great Britain	765,110,000	100
France	702,964,000	92
United States	375,656,000	49

Figure 14 shows graphically the achievement of America in manufacturing propellants and explosives.

In the production of artillery ammunition, a comparison with France and Great Britain shows that our monthly rate

in turning out unfilled rounds of ammunition at the end of the war was 7,044,000 rounds, as against 7,748,000 rounds for Great Britain and 6,661,000 rounds for France. In producing complete rounds of artillery ammunition, our monthly rate at the signing of the armistice was 2,429,000 rounds; that of Great Britain was 7,347,000 rounds and that of France 7,638,000 rounds. In the nineteen months of our participation in the war our production of unfilled rounds in ammunition was 38,623,000 rounds; that of France was 156,170,000 rounds and that of Great Britain 138,357,000 rounds. In that time we had produced 17,260,000 complete rounds; France had produced 149,827,000, and Great Britain 121,739,000.

The explosives industry in the United States, which had always been large, experienced a tremendous expansion after 1914 in response to the needs of the Allies for ammunition; yet this growth was nothing compared to what the industry was to know after America's entrance into the war in 1917. Our ordnance people found an industry operating at full capacity with a trained *personnel* all too small for the work demanded of the manufacturers under their contracts with the Allies. It was the first concern in the Ordnance Department to thin out this limited force of experts and distribute them among the new plants which began to spring up almost as soon as the United States became a belligerent. Then, by assigning chemists, engineers, and other specialists from the technical callings to work in these new plants under the direction of the men already trained in the manufacture of explosives, the War Department created as quickly as possible a vastly enlarged force of competent operators and supervisors for the production of these most necessary commodities.

Under the agreement with the French and British, not only did existing war production for export have to be kept up, but this production had to be expanded; and, outside all this activity, the American Government had to build up an industry for the production of explosives for its own army uses. Such a program meant, of course, the erection of many entirely new manufacturing plants and the creation of trained forces to

operate the new facilities. In addition we were required to bring into existence huge factories for loading the explosives into shell, into cartridges, and into bags. In all, the Government and its contractors began the construction of fifty-three new plants in the ammunition industry, at the cost of approximately $360,000,000. A great part of this new capacity was brought into operation before the armistice was signed.

RAW MATERIALS

In the decade preceding the belligerency of the United States in the World War, our Army, for both its mobile and its coast artillery, had depended upon ammonium picrate as the high explosive used as its bursting charge in shell. In the army vernacular this was called Explosive D. A highly efficient commodity was Explosive D, and one with which the Army was satisfied in every way; but in the effort to obtain the greatest quantity of explosives possible, other considerations than the one of supreme merit had to be taken into account. During the war we loaded shell for American use not only with ammonium picrate, but also with two other high explosives: trinitrotoluol—T. N. T., as it is commonly called—and amatol.

Amatol was a British development, an explosive brought into extensive use during the European conflict. It is a mixture of T. N. T. and ammonium nitrate. In actual service on the battle field it proved to be entirely satisfactory in high-explosive shell. T. N. T., itself a deadly and efficient explosive, was expensive and hard to obtain. Ammonium nitrate could be produced here in large quantities at the war chemical factories then springing up. Therefore, to conserve T. N. T. and obtain the greatest possible quantity of high explosives the Ordnance Department adopted amatol and used it extensively in shell for guns of medium size.

In theory, the policy of the Ordnance Department for the use of high explosives came to be as follows:

T. N. T. for shell up to and including those for the 4.7-inch guns;

Amatol for shell of calibers between 4.7-inch and 9.5-inch, including the latter;

Ammonium picrate (Explosive D) for shell of 10-inch caliber and larger.

This loading scheme was followed, not always rigidly, but only as the supplies of the three high explosives warranted. As a matter of record, amatol was loaded into shell of all sizes, and so was T. N. T., but Explosive D was never used in shell smaller than the 10-inch size.

In building up the war explosives supplies our first concern was to arrange for the production of immense quantities of T. N. T. and ammonium nitrate. It was soon discovered that the War Department itself would have to foster and encourage the production of the raw materials which went into these and other explosives used in army ammunition. Toluol, phenol, caustic soda, sodium nitrate, sulphuric acid, nitric acid, ammonia liquor—these chemicals are all raw materials of the explosive industry; and it was necessary for the Government greatly to increase the means of obtaining all of them. In addition we faced the bugbear of a possible failure of the cotton planters to provide linters in sufficient quantity to guarantee us an adequate supply of cellulose, a chief ingredient of smokeless powder. Hence one of the problems of the Ordnance Department was to work experimentally in the effort to produce a substitute for cotton in the production of cellulose. We had heard for years that the Germans, in the manufacture of smokeless powder, were using cellulose produced from wood pulp. Our experimenters worked in the same direction to produce a wood pulp in suitable form for nitration. It was the expectation that, if the war lasted and we were forced to this substitute, we should find our wood in the stumps of cut-over timber lands and in swamp lands of the South and Southwest. The war ended before we were forced to that extremity.

It quickly transpired that the chief of the problems in the supply of raw materials for explosives was that of toluol. Toluol is the basic raw material from which T. N. T. is made.

T. N. T. alone and amatol, of which T. N. T. is a principal component, were to fill all the shell to be used by our mobile artillery, Explosive D (ammonium picrate) being fired only by the railway guns. But toluol was a product difficult to obtain. Before 1914 the sole source of toluol in the United States had been the by-product coke ovens. In the year 1914 American ovens of this sort could produce a maximum of 700,000 pounds of toluol a month. The war in Europe greatly stimulated the American production of toluol; the infant, but rapidly growing, dye industry of this country added its demand for the commodity; and there was a growing tendency in the United States toward a national economy that no longer wasted the valuable by-products of industry. These three factors combined to increase the use of by-produce coke ovens in the United States, so that by April, 1917, the domestic capacity for the production of oven toluol had increased to 6,000,000 pounds a month. The Ordnance Department succeeded during the war in doubling this rate, raising the production from this source at the time of the armistice to about 12,000,000 pounds a month. Simultaneously the average price declined to 21 cents a pound from a price which, not so many months before, had been as high as $1 a pound.

Yet even this increased production did little more than meet the immediate needs, and the attention of the Ordnance Department turned to consideration of the supply of toluol for 1919 and 1920, assuming that the war would last that length of time and that the American military establishment would reach correspondingly tremendous size and consuming capacity. By piling contracts for raw toluol upon the coke companies, the Department warranted the latter in beginning the construction of new by-product ovens by hundreds. The augmented supply for 1919 was guaranteed by new oven installations providing increased output as shown on next page.

Here was additional production, to start in 1919, that would add to the national producing capacity over 18,000,000 pounds of toluol per annum. It cost the manufacturers about $30,000,000 to install these additional ovens. For 1920 there was to be

1919 Toluol Augmentation

Company	Capacity Pounds per year
Jones & Laughlin Steel Company, Pittsburg, Pennsylvania	5,770,160
The Sloss-Sheffield Company, Birmingham, Alabama	2,019,556
United States Steel Corporation, Clairton, Pennsylvania	2,308,064
International Harvester Company, Chicago, Illinois	1,586,794
United States Steel Corporation, Birmingham, Alabama	2,019,556
Rainey-Wood Company, Swedeland, Pennsylvania	2,163,810
The Seaboard By-Product Company, Jersey City, New Jersey	1,081,905
Pittsburg Crucible Steel Company, Midland, Pennsylvania	2,019,556

a further augmentation of the oven toluol supply, for in the summer of 1918 the War Department arranged for the construction of 320 additional ovens that, coming into operation about the beginning of 1920, would add 600,000 pounds of toluol a month to the supply. The 1920 plant increment was to be as follows:

Company	Date of contract	Estimated cost	Estimated time of completion
Donner Steel Company, Buffalo, New York	May, 1918	$6,000,000	Mar., 1920
Birmingham Coke Company, Birmingham, Alabama	July, 1918	2,500,000	Oct., 1919
Domestic Coke Corporation, Fairmont, West Virginia	Sept., 1918	2,700,000	Nov., 1919
Domestic Coke Corporation, Cleveland, Ohio	July, 1918	1,500,000	Feb., 1920
International Coal Products Corporation, Clinchfield, Virginia	May, 1918	2,000,000	Aug., 1919

The production of toluol by the distillation of coal and wood in by-product ovens was, however, a tedious way of obtaining the chemical. It takes a long time to construct a by-product oven, and the output of toluol to the oven is not large. About the time war broke out in Europe, industrial science had

begun to look for other sources of the important commodity. There was, for instance, ordinary artificial gas, which contains considerable quantities of toluol. These quantities represented, to be sure, considerable heating and illuminating power; but it was better that the householders of the United States should put up with an inferior fuel for a time than that the war powder industry should contend with a shortage in toluol. In the summer of 1917, investigators for the Ordnance Department studied plans for stripping artificial gas of its toluol content. They rendered a report in October, 1917, in which they reported the plan feasible, the process relatively simple, and the machinery easy to obtain; and late in November the artificial gas companies of a dozen leading American cities, in pursuance of contracts with the Government, began installing toluol plants. The first of these plants came into operation in April, 1918—a remarkable record, considering that the operating *personnel* had to be enlisted and trained in this entirely new branch of industrial chemistry. The total cost of the installations at the various gas plants was about $7,500,000. Contracts were made with gas companies in New York and Brooklyn, Boston, New Haven, Albany, Utica, Elizabeth, New Jersey, Washington, D. C., Detroit, St. Louis, New Orleans, Denver, and Seattle. The people dwelling in these cities unconsciously contributed to the successful termination of the war by using for their lighting and heating needs artificial gas considerably below normal quality, because of the removal of its toluol. Tests in New York City showed that the extraction of toluol reduced the gas in heat value approximately 6 per cent and its candle power from the index figure 22 to 16.

Crude petroleum and some of its principal distillates offered most promise of all as a source of toluol. Toluol may be obtained from petroleum by "cracking," a treatment of the oil under high pressure and in high temperature. There were several processes of applying this treatment, of which the Ordnance Department finally approved three and awarded contracts under each.

The first and most important of the three was the process owned by the General Petroleum Company of Los Angeles, California. This method used a petroleum distillate which existed in large quantities and which, when subjected to the process, yielded 6 per cent of its volume as toluol. The company erected at Los Angeles and at San Francisco two large plants costing approximately $5,000,000. These plants had a monthly capacity of 3,000,000 pounds of toluol, or a full one-fourth of the total national supply at its largest development.

Another process for obtaining toluol from petroleum derivatives was known as the Rittman process. It was evolved by a scientist of the U. S. Bureau of Mines. This was also a cracking process, and it was demonstrated by tests to be capable of operation under practical factory conditions. At a site on Neville Island near Pittsburg a plant for the production of toluol by the Rittman process was erected. This plant had begun producing the chemical by the time the armistice was signed.

A third process officially approved was known as the Hall process. This method obtained toluol by cracking solvent naphtha by a secret mechanical system. The scheme was put into operation on a small scale during 1918 at the plant of the Standard Oil Company at Bayonne, New Jersey.

Picric acid was an explosive manufactured extensively during the war under the direction of our Ordnance Department, but principally on account of the French Government. One of the essential raw materials used in producing picric acid is the chemical phenol. Accordingly phenol was a commodity to the increased production of which the Ordnance Department had to bend its energies. When we entered the war, American chemical plants were producing phenol at the rate of 670,000 pounds a month. In October, 1918, our plants were producing 13,000,000 pounds a month, and in that time the price of phenol had dropped from 46 to 31 cents a pound.

Sulphuric acid was another commodity used in heavy quantities by the powder factories. The acid had experienced a

phenomenal increase in price, jumping from the prewar price of $14 a ton to $60 early in 1917. The sulphur in the acid in normal times had been obtained largely from pyrites imported from Spain, but the submarine blockade greatly hindered this trade. Consequently our chemical factories had to rely principally upon the sulphur deposits in Texas and Louisiana. In the early part of 1918 there was a destructive storm which temporarily curtailed the production of sulphur from the Louisiana deposits, but production was resumed speedily enough so that the industry suffered no embarrassment.

As most persons know, nitrates are indispensable to the production of explosives. The principal natural source of nitrates is in Chile. The operations of enemy submarines, by reducing the efficiency of ocean shipping, put a limitation upon our importations of sodium nitrate from Chile. The Government had no intention, however, of relying upon this uncertain supply, particularly since it was conceivable that a complete blockade of our coast might shut off trade with South America altogether. In modern times science had learned to fix in usable form the nitrogen which constitutes four-fifths of the air we breathe; and one of the first war acts of the Government was to authorize the construction of air-nitrogen fixation plants at Sheffield and at Muscle Shoals, Alabama. These two plants, which used different processes, were just coming into production when the armistice was signed.

The Government did not rest on this prospective supply, but began the construction also of two other great fixation plants, one at Toledo and one at Cincinnati, Ohio. The building project called for the expenditure of about $25,000,000 at each place. When the armistice was signed the Government terminated the incompleted projects.

These instances, though they by no means include all activities of the War Department in procuring raw materials for the explosives manufacturing program, indicate the extent to which the Government was ready to involve itself in aid of the ammunition industry. Yet the procurement of the raw mate-

rials was but the first step in developing the industry. The next was to build up the manufacture of the powders themselves.

The artillerist divides explosives into two main sorts, each with its own distinct function. Explosives of the one sort are known as propellants. They explode and send the bullet from the rifle or the shell from the cannon. Explosives of the other sort, often designated by the initials "H. E.," are known as high explosives. The high explosives are packed in the shell themselves, and they cause the shell to burst at their objectives. The manufacture and utilization of propellants and the manufacture and utilization of high explosives all offered their special problems.

PROPELLANTS

PROPELLANTS include both smokeless powder and black or smoke-producing powder. Of these, smokeless powder was much the more important during the war. In 1914, the total producing capacity of all the powder mills in the United States was approximately 1,500,000 pounds of smokeless powder every month. Under the stimulation of war orders from Europe this capacity had grown until, by the spring of 1917, when we came into the affair, it had increased perhaps thirty times. Once our officers understood the situation in Europe and struck the agreement with the Allies that put upon us the burden of supplying a great part of the explosives to be used by the anti-German forces on the western front, the early 1917 capacity of America for producing smokeless powder, great as it had seemed to be, looked small indeed compared to what we should have to attain.

The expansion to be sought was such that the Government could not think of relying upon private enterprise to fill the need. The War Department itself constructed two of the largest smokeless-powder factories in the world. One of these was called the Old Hickory plant, because it was located almost on the site of Andrew Jackson's old home at Nashville, Tennessee. The other, built on a site near Charleston, West Virginia, was called the Nitro powder plant.

Photo from Ordnance Department

SMOKELESS POWDER ON CONVEYOR AT POWDER FACTORY

Photo from Willys-Overland, Inc.

CASTING SHELL IN FLASKS

Photo from Winslow Brothers Company

FURNACES AND QUENCHING TANKS FOR HEAT-TREATING SHELL

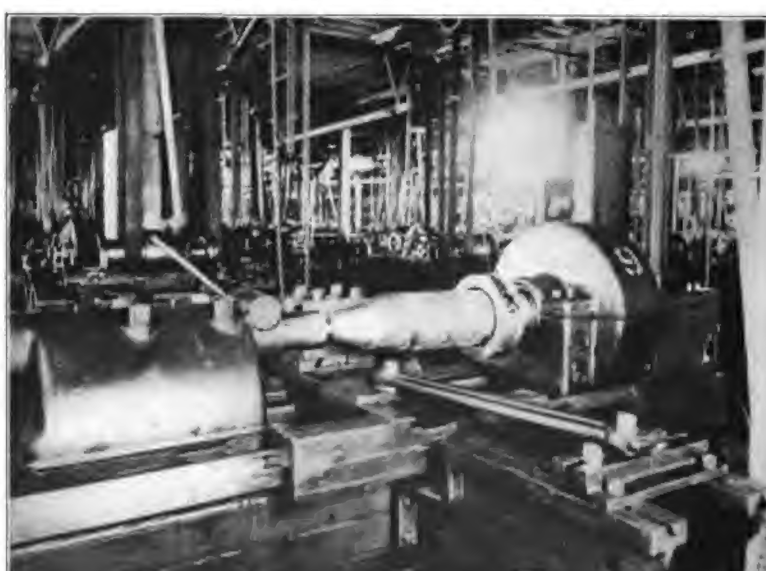


Photo from Willys-Overland, Inc.

ROUGH-TURNING NOSE OF 8-INCH SHELL

The Old Hickory plant, the larger and more complete of the two, was probably the biggest factory of its kind ever built. It was entirely self-contained, an unusual thing in factories of its sort; that is, it took the initial raw material of crude cotton, produced at the plant itself the acid and the solvents used, and put the cotton through every process until the final product, smokeless powder, was turned out ready for use. In the plant nine powder lines (each chain of machinery through which the raw materials pass to be converted into smokeless powder is called a powder line) were projected, each one to have a capacity of 100,000 pounds of powder a day. The plans thus gave the factory an indicated daily capacity of 900,000 pounds; but the plant performed beyond expectations, and indications soon were that its ultimate capacity would reach 1,000,000 pounds a day. In other words, this single government factory in full operation would produce two-thirds as much smokeless powder in a day as all the powder mills in the United States in 1914 (and the industry ranked as great then) could turn out in a month.

The Old Hickory plant cost in the neighborhood of $90,000,000. It was constructed by the DuPont Engineering Company under a contract with the War Department. The contract bound the concern not only to construct the plant, but also to operate it for six months after its completion. It was expected that the first powder line in the plant would go into operation on September 15, 1918, seven and a half months after the contract was signed. The contractors broke ground at Old Hickory on March 8, 1918, and pushed the work so efficiently that on July 1, seventy-five days ahead of schedule, the first powder line went into operation.

The Old Hickory plant spread out over an area of 5,000 acres, on which, in addition to the powder plant itself, was built a whole city for the housing of twenty-odd thousand people, the operatives and their families—a city complete with schools, churches, theatres, sanitation, and all other elements that make up the physical equipment of a modern urban community. Besides the powder plant itself, there were built a

number of sub-process plants for purifying the cotton and for manufacturing sulphuric acid, nitric acid, and other chemicals used by the plant. Each one of these sub-plants would have been in normal times an undertaking of sufficient size to attract the attention of the chemical industry.

By the date of the armistice the Old Hickory factory was more than 90 per cent complete, and it was operating at more than half its estimated capacity. It had produced 6,000,000 pounds of powder more than had been expected under the terms of the contract and had reached a total daily capacity of nearly 500,000 pounds of smokeless powder.

The Nitro plant was somewhat smaller. Its completed capacity was to be 625,000 pounds of smokeless powder a day. It was built by a private contractor, the Thompson-Starrett Company of New York, under direct government supervision. The ground was broken February 1. The Ordnance Department contracted with the Hercules Powder Company to operate the plant, and at the date of the armistice the factory was turning out over 100,000 pounds of smokeless powder a day, with the prospect of a speedy increase. As at the Old Hickory plant, a town of considerable size and also many sub-process plants were built.

The negotiations leading up to the construction of these two establishments formed an interesting business episode and brought into the War Department's organization an eminent business man. These powder-mill projects were a tremendous undertaking. The plants were the biggest of the sort ever put down on paper, and it was realized that only men and concerns of the widest experience could hope to carry the plan through successfully. Naturally the Department turned to the DuPonts as the ones whose experience in great undertakings of the sort gave the best guarantee of success. The DuPonts figured on both jobs, but quoted terms which the Government considered out of reason. The war department executives thereupon approached Mr. D. C. Jackling, the copper man, and one of the best-known figures in the industrial world. At great personal sacrifice Mr. Jackling agreed to accept the posi-

tion of Director of United States Government Explosive Plants at a salary of one dollar a year. Mr. Jackling at once contracted with the Thompson-Starrett Company to build the Nitro plant under his direction. He was firmly of the opinion, however, that the Government could best be served if the DuPonts undertook the construction of the larger project at Old Hickory, and he was able to come to an agreement with the company that was satisfactory to the Government.

One difficulty that seemed to stand in the way of a speedily increased production of smokeless powder was the fact that the powder, to be safe for use, had to dry in warm air for a long period after it came from the machinery. Before 1917 a powder company would not have thought of selling small-caliber smokeless powder that had dried less than six weeks; and for the powder used in propelling large-caliber shell a drying period of nine months was usual. Such methods were out of the question in war times. The Ordnance Department authorized a short-cut process of completion known as water-drying. By this method the fresh powder is immersed in warm water for about three days, and the water is then dried out of the powder by centrifugal force, with a final finishing drying in hot air. The treatment reduced the drying time to four days for small-caliber powder and twenty-two days for powder for the larger guns.

Just as the armistice came, the experimenters were trying out an entirely new drying process, known as the Nash or alcohol-drying process. The tests made it seem that this method was a great improvement in safety, cost, and time. The indications were that the drying could be measured in hours rather than in days. The process also seemingly ensured a tougher and more uniform grade of powder.

The production of smokeless powder in great quantities reduced its cost in spite of the mounting prices for labor and for many raw materials. In April, 1917, smokeless powder cost 80 cents a pound for the sort used in small-arms ammunition and 53 cents a pound for that used in cannon. Nineteen months later the prices were respectively 62 cents and 41 cents.

Black powder, which also ranks as a propellant, did not have nearly so extensive a use in the war as smokeless powder, and its production presented little difficulty except for the fact that the makers faced a shortage in potassium nitrate, one of the principal ingredients. Germany is the principal world source of potash. When the armistice came, experiments were going on which anticipated the substitution of sodium nitrate, the Chilean product, for potassium nitrate; and, although it was never necessary to make such a substitution, the indications were that it could be successfully done. When the fighting ended, American factories were producing black powder for the Army at the rate of 840,000 pounds a month, at a cost of 25 cents a pound.

In general, the goal toward which we were straining was a production of one billion pounds of smokeless powder in the year 1919. To have attained this production would have been to double the rate of output reached just before the armistice. We expected to use two-thirds of this powder in our own guns and supply the rest to the armies of the Allies.

LOADING THE PROPELLANTS

When the propellant powder—that is, the smokeless and black powders used for throwing bullets and shell from guns—had been produced, it remained still to load it into cartridge cases behind the bullets and shell of fixed ammunition, or else in bags used for charging the guns of the larger calibers. The loading problem ramified into three branches. One was loading propellant powder into cartridges used in small arms—in rifles, pistols, and revolvers. This sort of fixed ammunition is familiar in appearance to everyone. But fixed ammunition—cartridge ammunition, in which the projectile is fixed into a metal container which also holds the propellant powder—was used in weapons larger than the small arms carried by the individual soldier. The 37-millimeter gun, for instance, fired cartridges of fixed ammunition, and so did the commonest artillery weapon of all, the 75-millimeter gun. In fact, all the mobile artillery, in size up to and including the 4.7-inch guns, fired

fixed ammunition—cartridges. The loading of these cartridges was another distinct branch of the ammunition business. In guns bigger than the 4.7-inch guns, the ammunition used was of the unfixed type—that is, the projectile, the shell itself, was first placed in the gun, and behind it the artillerymen inserted a propellant charge of smokeless powder packed in bags, the size of the charge being regulated according to the range desired. It was the task of the Ordnance Department in its own factories and through its contractors to fill these powder bags, and the operation of filling them—the third and final branch of the loading problem—was one of extreme precision and delicacy.

From the powder mills the smokeless powder was shipped to the bag-loading plants in bulk. Meanwhile another large manufacturing operation had been going on in the textile mills, which were making silken bags and forwarding them to the loading plants. Silk was used because any other suitable fabric produces a flash at the muzzle of the gun. The loading plants also required large numbers of metal and fiber containers into which the loaded bags were packed for overseas shipment, not to be unpacked until they reached the battle field.

There could be no guesswork about loading powder bags. A sufficient number of errors in loading the bags might possibly cause the loss of a battle. The battery commander, having figured his range and made ready to drop high-explosive shell on an enemy battery, had to know exactly how much propellant powder he had behind his shell. If the bags were overweight, then his mathematical calculations would fail him, and he would overshoot his mark; and if there were less powder in the bags than he calculated upon, he might drop shell in the midst of his own advancing troops.

The Government constructed three enormous bag-loading plants, one at Woodbury, New Jersey, another at Tullytown, Pennsylvania, and the third on the historic battle ground at Seven Pines, Virginia. These plants were built at a cost of $5,000,000 to $6,000,000 each, and they were each designed to load 20,000 bags a day, although each plant before the

armistice proved to be able to double this output by using two shifts of operators. The plants were erected in a remarkably short time. At Woodbury, New Jersey, the work of construction did not start until March 19, 1918, but the plant was ready to operate on May 28 and actually started operating on June 15. The work of constructing the other two plants was almost equally swift, and by the end of August, 1918, all three were in operation.

The operatives at the bag-loading plants were principally women. There were about 7,000 workers employed at each plant. Because of the danger of the work, these institutions had to be placed remotely from settled communities; and therefore it became necessary to provide special housing facilities at the plants, a work undertaken either by the War Department or by the United States Industrial Housing Corporation. At Tullytown these facilities included seventy bungalows, thirteen other residences, and half a dozen ninety-eight-room dormitories.

The work of loading propellants into small-arms ammunition was relatively simple, the Frankford Arsenal and the expanded commercial cartridge factories being able to take care of the enlarged program.

In all, nearly 20,000,000 pounds of powder were loaded into small-arms ammunition; approximately 33,000,000 pounds into fixed ammunition; and an almost equal quantity into bags, which were packed for shipment abroad.

HIGH EXPLOSIVES

The manufacture of high explosives proved to be much more difficult than making propellant powder, as the final production figures hint. During the war period we produced nearly twice as much smokeless powder as we did high-explosive, although in the autumn of 1918 the rate of production of high explosives in the United States had passed that of smokeless powder.

Best known to the public of all the high explosives used by the belligerents in the World War was trinitrotoluol—

T. N. T. This substance is a product of modern industrial chemistry, but as a commodity it did not rank high in American commerce before 1914. When the World War broke out in Europe the American production of T. N. T. was approximately 600,000 pounds a month, in varying grades of purity. Nearly all this output was used by powder mills in the manufacture of explosives for blasting purposes. The demands of the Allies for high explosives had a degree of stimulating effect upon the manufacture of T. N. T. in this country, but not so much as might be supposed; for when we declared war in the spring of 1917, the American chemical works were still taking care of the industrial demand for the commodity and in addition were supplying about 1,000,000 pounds of T. N. T. a month for use in the military operations in Europe.

The energy of the War Department, put behind the production of this highly important chemical during the nineteen months of our active belligerency, increased the American production of T. N. T. sixteen times, so that in November, 1918, we were producing it at the rate of 16,000,000 pounds a month for war purposes alone. The price of T. N. T., like that of many other commodities whose production increased during the war period, fell as the output expanded. When we came into the war the average price was $1 a pound. Thereafter raw materials grew scarcer and labor costs and other costs mounted; yet tremendous quantity production overcame these factors and brought down the price eventually to 26½ cents.

The expanded production of T. N. T. was largely brought about by private manufacturers working to meet enormous government contracts. Yet the Government never rested content with this private commercial expansion: looking far into the future, it began the construction of two large federal plants for the manufacture of the chemical. One of these, located at Racine, Wisconsin, was to have a capacity of 4,000,000 pounds of T. N. T. a month. The other one, at Giant, California, contemplated a production of 2,000,000 pounds a month. Here were two purely governmental institutions which, had the war continued, would of themselves have pro-

duced more than one-third as much T. N. T. as was being turned out on the date of the armistice by all the private factories in the United States, fostered and encouraged as they were by enormous orders and by an insatiable war demand.

The manufacture of T. N. T. is a dangerous operation, particularly when it is carried on at top speed by forces of operatives relatively inexperienced. Under the circumstances the toll of life taken in the production of our high explosives was remarkably small. The only two explosions of any magnitude that occurred in high-explosives mills during the war took place in T. N. T. plants. In May, 1918, there was an explosion in the factory of the Ætna Explosives Company, at Oakdale, Pennsylvania, that cost the lives of a hundred persons. A few weeks later sixty operatives were killed in an explosion in the plant of the Semet-Solvay Company, at Split Rock, New York. Both of these plants were operating on contracts to deliver T. N. T. to the Allies.

The shell-loading schedule of the Ordnance Department, it should be remembered, called for the loading of shell for all the larger-caliber field guns with the British high explosive, amatol. Among the weapons in this class were the widely used 155-millimeter guns and howitzers. It was evident that we should have to produce great quantities of amatol, although it was an explosive practically new to the experience of our powder makers. Accordingly, along with the expanded production of T. N. T. came a vast development of the manufacture of ammonium nitrate, the other principal ingredient of amatol. Ammonium nitrate had long been a common commodity in our chemical industry. It was widely used in the manufacture of commercial explosives. Prior to 1914 the American output of ammonium nitrate amounted to about 58,000,000 pounds a year. The expansion due to the demand of the Allies had by the early spring of 1917 increased the American production by something more than 20,000,000 pounds a year.

When we entered the war the Ordnance Department found in existence American facilities for turning out about 80,000,-

000 pounds of ammonium nitrate yearly. The supply, though large, was clearly insufficient for our needs, particularly as it was necessary under the Interallied Ordnance Agreement to maintain the supply of ammonium nitrate which our factories had been furnishing to the British Government, and even to increase it. Therefore, while utilizing every bit of the commercial capacity and encouraging the expansion of the private production of ammonium nitrate, the Ordnance Department set out upon the project to build for itself an enormous ammonium nitrate plant at Perryville, Maryland.

This plant was put up under the supervision of the Atlas Powder Company and operated by that concern under an agreement with the Government. The factory was erected and equipped in about four months in the spring of 1918, coming into production by the middle of July. Since all the buildings were absolutely fireproof, this was an extraordinarily swift job of construction. It is interesting to note that the work of building the plant began before the operatives in this country were familiar with the manufacturing process to be used. In England there had been developed an admirable method for manufacturing ammonium nitrate, known as the Brunner-Mond process. In this process ammonium nitrate is produced by the double decomposition of ammonium sulphate and sodium nitrate. Late in 1917 the Atlas people sent several chemists and other technical experts to England to study the manufacturing process. They returned a few weeks later, and on the basis of their report the equipment of the Perryville plant was prepared.

The output of ammonium nitrate under the Brunner-Mond process at Perryville reached, before the armistice, the astonishing figure of 452,000 pounds a day—a rate of production that would turn out nearly 140,000,000 pounds of the product in a year. In other words, at this one plant was developed an ammonium-nitrate-producing capacity nearly twice that of the entire chemical industry of the United States.

Ammonium nitrate is a secondary product, dependent upon the supply of nitrogen in usable chemical form. The Chilean

deposits were, of course, the principal source of nitrates; but the various nitrogen fixation projects included in the ordnance program guaranteed us eventually a domestic nitrogen supply that would make the country self-contained. The two nitrogen plants at Muscle Shoals, Alabama, and Sheffield, Alabama, were equipped to produce nitrogen in the form of ammonium nitrate which could be used directly by the powder factories. Before the date of the armistice these plants added their output to the total production of the indispensable commodity. The total American capacity for producing ammonium nitrate, including both the private and the government plants, reached the figure of 20,000,000 pounds a month.

During the war the French Army used picric acid as a high explosive. In the agreement with the French we engaged to pay largely in picric acid for the purchases of French field guns and shell that were to equip the artillery regiments of the A. E. F. until the new American ordnance could reach the front. To keep this agreement the Ordnance Department had to let large contracts for the production of picric acid by American explosives factories. The acid was produced in accordance with French specifications and was subject to joint inspection by our officers and those of the French. It will be remembered that, although our Army used no picric acid directly, the chemical was one of the prime raw materials used in producing ammonium picrate, Explosive D, the filler in shell fired by our 10-inch guns and larger. Picric acid, too, was consumed heavily by the Chemical Warfare Service in the manufacture of the common war gas chlorpicrin. Consequently it was necessary to turn out enormous quantities of picric acid, and the production actually increased from the 600,000 pounds monthly of November, 1917, to a monthly production a year later of over 11,000,000 pounds, or about eighteen times. The expansion was nearly all accomplished in private chemical plants. Looking to a future supply on a greatly expanded scale, the Government authorized and began the construction of three picric acid plants of its own—one at Picron, near Little Rock, Arkansas, to be operated by the Davis

Chemical Corporation; another at Savannah, Georgia, to be operated by the Butterworth-Judson Corporation; and the third at Grand Rapids, Michigan, to be operated by the Semet-Solvay Company. Each of these plants was to have a capacity of 14,500,000 pounds of picric acid a month, or more than the entire private industry in the United States could produce in equal time. The factory at Picron was the only one to come into any production before the armistice was signed.

Explosive D was produced by the ammoniation of picric acid. In May, 1917, the American average monthly production of this explosive was 53,000 pounds; by November, 1918, the output had been increased to 950,000 pounds a month, an expansion carried on entirely in privately owned plants.

In addition to these major explosives used as the charges for shell, it was necessary for the Ordnance Department to procure explosives of other types for use in caps, detonators, and boosters. The use of the booster will be explained in detail a little later on; here it is enough to say that it is a charge of explosive inserted within the main bursting charge in shell to accelerate the rate of the explosion. The explosives used in boosters and detonators were more sensitive than the explosives of the shell proper and exploded at a more rapid rate.

The principal explosive used by the Ordnance Department for booster charges was tetryl. Tetryl is more sensitive than T. N. T. or amatol and has a higher rate of detonation. At the beginning of American belligerency the national capacity for producing tetryl was less than 9,000 pounds a month. This capacity was increased before the armistice to 160,000 pounds monthly, the cost registering a decline from $1.30 a pound to 90 cents. The expansion was carried out entirely by two private concerns, the DuPont Powder Company and the Bethlehem Loading Company. The Government planned for an immensely increased capacity for producing tetryl and authorized the construction of a tetryl plant at Senter, Michigan. This unit was to be operated by the Atlas Powder Company and was to have a monthly capacity of 250,000 pounds.

No production had started at the Senter plant before the armistice.

The Russian Government had been securing from a manufacturer in the United States, the Ætna Powder Company, another highly sensitive and rapid explosive for use in loading boosters and fuses. This was tetranitroaniline, better known as T. N. A. The plant at Noblestown, Pennsylvania, where the Russian T. N. A. was being manufactured by the Ætna Company, was erased from the landscape by an explosion shortly after our declaration of war, and there were no other facilities in the United States for the production of the explosive. Ordnance officers who had been testing the substance had come to the conclusion that, for boosters, T. N. A. was the equal of tetryl. The patent rights for the manufacture of T. N. A. were held by Dr. Bernhardt Jacques Flurschein, and with him the Ordnance Department entered a contract. The next step was to erect a government T. N. A. plant on the factory grounds of the Calco Chemical Company at Boundbrook, New Jersey, the plant to be operated by the company on a cost-plus basis. This mill came into operation shortly before the date of the armistice and produced about 8,000 pounds of T. N. A.

The Ordnance Department used a still more sensitive and rapid explosive, mercury fulminate, in caps, primers, and detonators. Three plants in the United States produced this commodity—the DuPont plant at Pompton Lakes, New Jersey, the Atlas powder plant at Tamaqua, Pennsylvania, and the Ætna powder plant at Kingston, New York. These concerns expanded their facilities to produce during 1918 a monthly average of 50,000 pounds of mercury fulminate. The explosive was costly, the Government paying an average of $3.21 a pound for it.

There was not enough T. N. T. and amatol in sight to fill our shell and leave a residue sufficient to take care of the tens of millions of grenades, bombs, and trench-mortar shell that the Government in 1917 set out to manufacture. Consequently the Ordnance Department began looking for other high explosives which could be manufactured in abundance, but which

would not compete with amatol and T. N. T. for raw materials. The officers found a satisfactory one in a nitrostarch explosive developed by the Trojan Powder Company at Allentown, Pennsylvania. This commodity, after thorough tests, was authorized as the filler for grenades and 3-inch trench-mortar shell. The Trojan Powder Company's explosive was produced by a secret process which no other manufacturer possessed, and therefore the Government was entirely dependent for its grenade and mortar-shell explosive upon this one source.

Quite aside from its merits as an explosive, nitrostarch had the advantages of both its cheapness and the fact that it drew upon raw materials which were fairly plentiful. On the average we paid 21.8 cents a pound for it. It also had the advantage of being easy to load. The production of nitrostarch began to expand greatly at the Trojan Company plant in the summer of 1918. In July of that year the concern produced about 840,000 pounds of it. By November they had run this production up to 1,720,000 pounds a month. We loaded nearly 20,000,000 hand and rifle grenades with nitrostarch explosive and nearly a million shell for the 3-inch trench mortars. Late in the war the DuPont Company developed a nitrostarch, known as grenite, which our Ordnance Department tested and approved.

Lyconite was a minor explosive produced for our Ordnance Department during the war. It was an invention of the DuPont Company. We used it in drop bombs. We also investigated anilite, a liquid explosive developed by the French; but although experimentation went on to make it a safer product, we never used any. The Department investigated explosives made of chlorates and perchlorates and developed several types that were considered satisfactory, but none of them got into production.

SHELL MANUFACTURE

While the high explosives were being produced, another great collateral manufacturing activity was in progress, one essential to the task of providing ammunition for our artillery. Be-

sides the powder, the Ordnance Department had to produce the shell themselves into which the high explosives should be loaded. At this point the Department stepped from the chemical and powder industries over into the metal-working industry. There it found difficulties quite unforeseen at the start of the war.

It is perhaps not generally understood that the shell-making industry, as we developed it during 1917 and 1918, was virtually a new branch of manufacture to the metal-working industries of the United States and to our ordnance experts. We had to build the industry from the ground up. That this was true was partially due to the fact that we abandoned shell of the type our army contractors had known and adopted shell radically unlike any which American guns had ever fired before 1917.

The old American shell had been largely of the base-fuse type—that is, the fuse was inserted into the shell at its base, resting upon the propelling powder when the shell was in the gun ready for firing. European practice, on the other hand, screwed the fuse into the nose of a shell, utilizing an attachment known as the adapter, to enable the artillerist in the field to insert the sort of fuse he desired.

The explosion of an H. E. shell is really a series of explosions. The process of the burst is about as follows: The firing pin strikes the percussion primer, which explodes the detonator. The detonator is filled with some easily detonated substance, such as fulminate of mercury. The concussion of this explosion sets off the charge held within the long tube which extends down the middle of the shell and which is known as the booster. The booster charge is a substance easily exploded, such as tetryl or tetranitroaniline (T. N. A.). The explosion of the booster jars off the main charge of the shell, T. N. T. or amatol. This system of detonator, booster, and main charge gives control of the explosives within the shell, safety in handling the shell, and complete explosion when the shell bursts. Without the action of the booster charge on the main charge of the shell, the latter would be only partially burned

when the shell exploded, and part of the main charge would thus waste itself in the open air.

The adapter is the metallic device that holds the booster and fuse and fastens them in the shell. The adapter, therefore, is a broad ring, screw-threaded both outside and inside. The inside diameter is uniform, so as to allow the same size of booster and fuse to be screwed into shell of different sizes. The outside diameters of the adapters vary with the sizes of the shell they are made to fit, the rings thus being thicker or thinner as may be required. Fuses of several sorts are employed by the modern artillerist; and into shell equipped with adapters, any fuse may be inserted in the field, right at the gun.

The boosters and adapters were what gave our manufacturers the trouble—unexpectedly, because the contrivances seemed at first glance to be simple, and it was thought that our metal-working factories would have no difficulty in coming into enormous production of them. The bitter fact proved to be that the delay in securing a sufficient number of boosters and adapters throughout the war period put a limitation upon our output of loaded shell.

When the war began our Ordnance Department went ahead with no thought other than that we should produce shell of the base-fuse type. On May 1, 1917, the Ordnance Department invited bids on its first war order for base-fuse shell for our 3-inch field guns. The bids were opened on May 15. The Council of National Defense, which had been mobilizing various metal-working plants of the United States and building up a potential shell-making industry, assisted in distributing the contracts, until eventually orders were out calling for the delivery of 9,000,000 rounds of 3-inch shell and shrapnel ammunition. We were about to ask for bids for manufacturing American-type shell and shrapnel for the other guns and howitzers when the French Military Mission arrived in the United States. Immediately the French proposed that we change our 3-inch and 6-inch guns to the 75-millimeter and 155-millimeter dimensions respectively and use ammunition from a common pool to which we should contribute.

This plan meant that all ammunition in use by the American and French armies, at any rate, must be interchangeable. It followed that we should have to adopt the French shell designs in our manufacturing program. The decision to do this was taken definitely on June 5, 1917. About this time also we had made arrangements with the British to produce for our own use the 8-inch and 9.2-inch howitzers of British design, making it desirable that the ammunition we should produce for these weapons should be interchangeable with British ammunition.

These important steps made necessary what was practically a complete rearrangement of our shell-manufacturing plans. Instead of going ahead with the production of shell of the American base-fuse type, we canceled the large orders that had already been placed, threw into the discard the arrangements made for the additional orders, and awaited the arrival from Europe of detail drawings of shell, boosters, and adapters, which we must have before we could make any start with the new program.

It was necessary in this period, too, to decide upon what foreign shell designs we should adopt. The Allies, and particularly the French, used shell of numerous different sorts—thin-walled and thick-walled and types ranging between these extremes, steel and semi-steel (a mixture of steel and iron), "streamline," and the more common blunt-nosed sort. In making our selection of designs we were guided by practical considerations of factory expediency.

Though in general we molded our industry into a foreign pattern, in one respect we were unwilling to follow European practice. Both the French and the British ammunition makers submitted their steel shell to drastic heat treatments which our metallurgists did not consider necessary, particularly in shell of the thick-walled type. Moreover, our manufacturers insisted (with complete truth) that there were not enough heat-treating facilities in the United States to take care of the shell program as projected, if we followed foreign practice in this particular. The result was that, while we adopted French and British shell completely in their designs, we permitted the

American industry to employ its own metallurgical practices. Possibly the foreign officers were dubious about the merit of the American shell produced in this fashion; but the justification of the Ordnance Department lies in the fact that later on the French, after test-firing 10,000 American-built 75-millimeter shell, pronounced them in every way the equal of French shell and admitted our product to the ammunition pool.

Though it adopted French and British specifications for shell, the Ordnance Department used American designs for fuses. Our fuses were approved by the Allied experts. In fact, it was generally agreed that the American time fuse was better than any other in use by the Allied side. The result of the decision to manufacture American-designed fuses was that our factories early came into quantity production of these essential elements. There never was a shortage of fuses.

No such success met the production of adapters and boosters. We had had no experience in their manufacture, and our lack of experience brought about numerous difficulties. Whenever the manufacture met trouble it was necessary either to await information from Europe before the production could go on again, or else to hold up the work until we resolved the difficulties by independent experiment.

From the beginning it was evident that for our war shell we could not rely on factories able to turn out completed shell or complete rounds of ammunition. The American plants capable of such complete manufacture were few in number. To utilize the metal-working industry to its greatest capacity, the program was to make the production of shell an assembling job and to scatter throughout the United States contracts large and small for the manufacture of shell parts. It was early realized that, with so many contractors bidding for steel forgings and other raw materials, prices would leap and shortages would occur. Therefore the Government itself went into the market and purchased raw materials for the shell makers, including castings and semi-finished components.

This is a fitting place to acknowledge the debt of the War Department to the War Industries Board. That organization

had many important duties; duties which grew in number and importance as time went on, until, as the armistice drew nigh, it was rapidly assuming the character and position of a directorate of national defense—a body superior in powers to both the War and Navy Departments. Among the many activities of the War Industries Board none was more important, and none was carried out with more efficiency, than the procuring of raw materials for the manufacture of munitions. In the procurement of raw materials for the powder and shell manufacture, the War Industries Board was particularly effective. Mr. Bernard M. Baruch, the director of the Board, took personal charge of the procurement of nitrates, and it was largely due to his persistence that an adequate number of ships were held in the South American nitrate trade, guaranteeing to us an ample reserve of Chilean nitrate for our powder manufacture. The War Industries Board led the way in developing the manufacturing resources for other raw materials used in the ammunition industry; and it was the agency which built up the manufacture of shell, for which it procured the raw metallic materials. The results of these efforts were shown in the final production figures. No branch of ordnance manufacture was so successful, from the standpoint of actual output, as the manufacture of powders and high explosives.

After overcoming almost innumerable obstacles, the United States eventually developed an enormous shell industry. The machine shops turned out, in all, something less than 12,000,000 shell for the 75-millimeter guns during the war. Of these, nearly 3,000,000 passed inspection in the month of October alone, a fact which shows the momentum finally attained. Over 7,000,000 adapters and boosters for 75-millimeter shell had been machined up to November 1, 1918, and of these nearly 3,000,000 passed inspection in October. Up to November 1, 1918, nearly a million 4.7-inch shell were produced complete and ready for loading, together with something over 600,000 adapters and boosters, which, moreover, could be used in shell of other sizes. Over 2,000,000 shell of the 155-millimeter size were produced ready for loading up to November

Photo from Willys-Overland, Inc.

MACHINING ROOM IN SHELL PLANT

Photo from Willys-Overland, Inc.

COMPLETING MANUFACTURE OF SHELL

Photo from S. A. Woods Machine Company

SHELL, WITHOUT FUSES, READY FOR GOVERNMENT INSPECTION

Photo from Willys-Overland, Inc.

SHELL READY FOR PACKING AND SHIPMENT

1, 1918, and over 2,500,000 boosters and adapters for shell of this size.

LOADING THE SHELL

After the high explosive was made and after the shell were produced complete with fuses, boosters, and adapters, there remained still to be accomplished a tremendous operation—loading the bursting charges into the shell.

Explosive D, the only shell filler handled by American ammunition makers on army account prior to 1917, was loaded into shell by hydraulic pressure. The adoption of nose-fuse shell and of the new explosives, amatol and T. N. T., made necessary the use of new methods of shell loading. In effect, the entire war industry of shell loading, as built up by the War Department after the declaration of war in 1917, was a new thing.

The first step was to arrange with various manufacturers of the United States to erect and equip new shell-loading plants—fourteen in all they numbered, before the armistice called a halt to the expansion. These plants were either entirely new projects, built at convenient locations by concerns some of which had had no previous experience in the work, or else installations added to existing munitions plants. Certain concerns with experience in the work built entirely new factories to handle government shell-loading contracts. The list as it existed on the day of the armistice was as follows:

Company	*Location*	*Total capacity daily (shell)*
T. A. Gillespie Loading Company	Morgan, New Jersey	47,000
T. A. Gillespie Loading Company	Parlin, New Jersey	25,000
T. A. Gillespie Loading Company	Runyon, New York	3,500
Poole Engineering & Machine Company	Texas, Maryland	15,000
United States Arsenal	Rock Island, Illinois	1,000
Sterling Motor Car Company	Brockton, Massachusetts	10,000
American Can Company	Kenilworth, New Jersey	20,000
Atlantic Loading Company	Amatol, New Jersey	53,500
Bethlehem Loading Company	Mays Landing, New Jersey	41,000
Bethlehem Loading Company	New Castle, Delaware	27,400
Bethlehem Loading Company	Redington, Pennsylvania	4,000
DuPont Engineering Company	Penniman, Virginia, G plant	41,000
DuPont Engineering Company	Penniman, Virginia, D plant	13,330
J. D. Evans Engineer Corporation	Old Bridge, New Jersey	30,000
Total		331,730

The common method of loading T. N. T. into shell was to heat the explosive to a molten state and then pour it in. The T. N. T. was melted in a steam-jacketed kettle, and the shell was brought up to the kettle and filled. But molten T. N. T., in solidifying, contracts in volume. If the shell were to be filled full of the liquid and then closed, the substance would develop cavities when cooling, and in that event the shell would not be filled to capacity. Incomplete detonation would probably result, or it might even fail to explode at all. To get around this difficulty the shell was filled in two operations. The first pouring filled the shell approximately two-thirds full of the molten T. N. T. The substance was then allowed to cool until a crust formed. This crust was then broken through and a second pouring plugged up the cavities and filled the shell full.

We manufactured and used amatol in two grades. One grade consisted of an equal mixture of ammonium nitrate and T. N. T. and was known as 50-50 amatol. Amatol of this grade could be melted and loaded into shell by the casting method used in loading pure T. N. T. The other amatol was called 80-20, and it consisted of 80 parts of ammonium nitrate and 20 parts of T. N. T. The loading of this mixture into shell was not so easy.

The original method employed for loading 80-20 amatol was to fill the shell by hand with the cold amatol and then with machinery press the explosive to the required density. But this was a process fraught with danger of explosion, and the British found that a safer way was to load the 80-20 amatol hot—not melted, but heated to the point where it became spongy and easily compressed. The shell was then filled with hot amatol, which was tamped by hand to the proper consistency. This method, though safer than the other, was tedious, slow, and ill adapted to quantity production.

The British industry then developed an automatic loader which was rapid and which entirely did away with handwork. The loader was known as the horizontal extruding machine. With this device the British factories were able to load 80-20 amatol into shell as large as those for 8-inch guns. The relatively few amatol shell used in guns of larger size were still filled by hand tamping.

The extruding machine took the amatol into a steam-jacketed hopper that fed the substance down through the funnel upon a worm screw. This screw ran down into the shell and was balanced by counterweights, so that the action of the screw would pack the explosive in the shell to any desired density, according to the adjustment of the weights. The Ordnance Department imported an extruding machine from England. American tool manufacturers pronounced it unsatisfactory from a constructional standpoint; and we designed a new machine, on the same principle, but capable of being built rapidly by our metal workers. The development of the American extruding machine occurred at the Picatinny Arsenal at

Dover, New Jersey, at the DuPont Experimental Station at Gibbstown, New Jersey, at the Morgan, New Jersey, plant of the T. A. Gillespie Loading Company, and at the Penniman, Virginia, plant of the DuPont Engineering Company.

As the screw of the extruding machine filled a shell, it lifted itself out, leaving behind a cavity in the amatol. This cavity was then filled up with molten T. N. T. In turn, a smaller cavity had to be produced in the T. N. T. core of the amatol charge to admit the booster. This cavity was produced by pouring the T. N. T. around a former the exact size of the booster, or by plunging the booster itself into the T. N. T. while it was still warm, or, a third method, by drilling out a cavity in the T. N. T. after it had cooled. There were frequent inspections of shell as they came from the loading machines. At regular intervals a split shell—that is, a shell which could be taken apart in two longitudinal sections—was run through the machine. This test shell was opened and examined; and, if defects in the loading were occurring, they could be remedied before any large number of shell had been filled.

GENERAL FACTS ABOUT AMMUNITION PRODUCTION

Smokeless powder used as a propellant charge would not betray the position of a field gun during daylight hours, but at night the flash of the explosion at the muzzle of the gun could be observed for many miles. Chemistry overcame this fault by producing a compound which, mixed with the propellant powder, would prevent the flash at the gun's muzzle. The Ordnance Department produced a large quantity of this flashless compound for mixing with propellant powder, either in the cartridge cases of the smaller calibers or in the silken bags of the unfixed ammunition. It was necessary for our artillery observers to be able to spot easily the explosions of shell fired from our own guns. Accordingly our powder makers mixed with amatol and other bursting charges in shell a smoke compound that made the puff of a burst conspicuous at a great distance.

One problem in the shell-manufacturing program was to

regulate the output of hundreds of millions of metallic parts so that they would come to the assembling plants and exist in reserve in the proper proportions.

With dozens upon dozens of metal-working factories turning out shell parts, the condition that all parts must fit perfectly put a burden upon the inspection service of the Ordnance Department. In a complete round of artillery ammunition, eighty dimensions had to be gauged. It required 180 master gauges to standardize the gauges used in making these eighty dimensions exact; and the actual number of gauges used in all the various steps in manufacturing a complete round was over five hundred. In addition to these, the government inspectors used over two hundred gauges in their work.

The shell-filling plants also assembled all fixed ammunition for the field artillery. Each filling plant accordingly had to have great storage capacity for propellant powder as well as for high explosives, and also machinery for handling the propellant powder and for loading the cartridge cases. Boosters and fuses were loaded at separate plants, but they were sent to the shell-filling factories to be packed for shipment overseas with the shell to which they belonged.

The cost of a 75-millimeter cartridge, complete with loaded shell, fuse, and propellant charge, was about $11. The high explosive in this shell, weighing a little over 1½ pounds, cost $1. The loading and assembling of the fixed round cost $4. The rest of the expense resided in the metal shell itself, in the propellant charge, and in the cartridge case. A loaded 155-millimeter shell, complete, cost about $30. The cost of the propellant charge was additional to this, since the 155's used unfixed ammunition.

There was always great danger of explosion in the shell-loading plants. Just before we entered the war an explosion destroyed the plant of the Canadian Car & Foundry Company, at Kingsland, New Jersey, killing many persons. Shortly before the armistice an explosion wiped out the Morgan, New Jersey, plant of the T. A. Gillespie Company and killed a hundred of the employees. In spite of the danger, it was not

FIGURE 15

Improvement of Field Guns since the Napoleonic Wars

Muzzle Velocity

Type	*Date*	*Feet per second*
Early rifled guns	1863-1870	1,090
Later rifled guns	1870-1893	1,466
Early quick firers	About 1900	1,696
Modern quick firers	1914-1918	1,770

Range with Shrapnel

		Yards
Smooth bores	1815-1850	1,257
Early rifled guns	1863-1870	2,004
Later rifled guns	1870-1893	4,120
Early quick firers	About 1900	6,160
Modern quick firers	1914-1918	6,500

Range with Shell

		Yards
Smooth bores	1815-1850	1,670
Early rifled guns	1863-1870	3,965
Later rifled guns	1870-1893	6,168
Early quick firers	About 1900	7,340
Modern quick firers	1914-1918	8,500
With streamline shell	1918-1919	12,130

unduly difficult to secure operatives for the factories. It is notable that fully half the persons employed in the shell plants were women.

STREAMLINE SHELL

As the war progressed, experts in the Ordnance Department were busy designing improvements for our ammunition, and some important results were attained. The Department had gathered into its service and commissioned as officers several eminent mathematicians who before the war had held professorships in various American universities. Among these were Professor Oswald Veblen of Princeton University and Professor F. R. Moulton, who, before accepting his commission, was professor of astronomy at the University of Chicago. These experts studied the flights and trajectories of shell and

by means of mathematical calculations were able eventually to work out new scientific contours for the missiles.

The modern shell as we knew it before the war was simply a metal cylinder cut off squarely at the base and roundly blunted at the nose. Every shell is zoned by a so-called rotating ring, a circular band of copper slightly uplifted above the surface of the shell to engage the rifling channels of the gun. The rotating ring therefore gives to the shell the whirl that keeps it from tumbling over and over and holds it accurately on its course in flight.

In the proof-firing of our 6-inch seacoast guns which were mounted and made mobile for the field artillery of the A. E. F., it was discovered that their fire was none too accurate. With the gun itself kept precisely at a designated range, the shell would fall at widely separated spots at the objective. The range-firing section, under Major Veblen at the Aberdeen Proving Ground, began studying the 6-inch shell itself to see if the fault lay there, and they discovered the cause of the inaccuracy in the copper rotating band. Although but a slight portion of this band was upraised above the surface of the shell's circumference, the enormous force exerted upon the projectile to start it from the gun actually caused the cold copper to "flow" backward. The result was that when the shell emerged from the muzzle of the gun it bore around its sides an entirely unsuspected and undesirable flange. This flange not only shortened the range of the shell by offering resistance to the air, but it was seldom uniform in its contour, a condition which gave rise to the idiosyncrasies of our 6-inch shell as they were fired.

The remedy was to redesign the rotating band, making it somewhat thicker in front. The "flow" of the copper was thus accommodated without causing any detrimental distortion of the projectile. The improvement made the 6-inch shell as accurate as any other and markedly increased its range.

The scientists were to make an even greater contribution to the efficiency of the 6-inch shell. This shell, like others in use by our artillery, was square-ended at the base. The designers,

in an effort to overcome air resistance to the projectile in flight, tapered the sides somewhat, making the shell boat-ended. Then they elongated the nose, bringing it out to a much sharper point. The result was a streamline design that proved to be extraordinarily successful when put to the test. The 6-inch gun could fire its old shell 17,000 yards. Experimental shell of the new design went 4,000 or 5,000 yards farther—that is, two or three miles were added to the range of an already powerful weapon. Nor was this design the first streamline shell design produced in America. On June 1, 1915, Mr. William King Richardson, an inventor of Leavenworth, Kansas, took out a patent on a long-pointed, boat-ended shell.

At that date, so far as is known, no foreign army had yet produced a streamline shell. Nevertheless the French were experimenting with streamline shell, all through the war, and they developed some successful types. We adopted the French streamline 75-millimeter shell and put it into production, calling it our Mark IV shell. The regular 75-millimeter shell produced in America, known as the Mark I 1900 shell, had a maximum range of 9,000 yards. The Mark IV shell proved to have a maximum range of 12,130 yards, the streamline design giving it an increase in range of well over a mile. With the manufacture of shell of this type beginning shortly before the armistice, America in the months that followed turned out several hundred thousand streamline shell for the 75-millimeter guns. These shell are part of our present war assets.

The French also built shell of semi-steel. The claim was that these shell would be more effective against troops than all-steel shell, because they would burst into finer fragments. We produced some of the semi-steel shell experimentally. In contour the semi-steel shell was a compromise between the old cylindrical shell and the ultra-streamline type, but it was easier to make than the latter.

It must be evident to anyone who has followed the narrative through this chapter that the war ammunition industry was not only tremendously big, but exceedingly intricate. In

importance it ranked with any major branch of munitions production. For emphasis, let us summarize and bring into brief space a statement of some of the activities of the Ordnance Department in building up the ammunition supply:

First, the procurement of raw materials for explosives—the prime requisite nitrogen, involving the creation of four great nitrogen fixation plants, two in Alabama that came into production, and two in Ohio, authorized, planned, partially built, but never completed. Then toluol, base of T. N. T., the most used high explosive, and the expansion of its supply, first by the construction of hundreds of by-product coke ovens, secondly by the creation of plants to strip the substance from illuminating gas, thirdly by extracting it from petroleum by three different processes. The manufacture of smokeless propellant powder, involving the construction for the Government of one powder plant that was the largest in the world, and another that was nearly as large. The development of a substitute for cotton linters in the production of cellulose for the smokeless-powder mills. Loading the propellant powder, requiring the construction of three great government bag-loading plants, each employing 7,000 operatives. The production of T. N. T., involving the construction of two large government plants. The production of the high explosive amatol, in pursuit of which the Government built the enormous ammonium nitrate plant at Perryville, Maryland. The production of picric acid and the construction therefor of three government mills of huge size. Then the adoption of French and British shell and the interknitting of American metal-working shops into an enormous shell-manufacturing industry. Finally, the development of the great manufacturing activity of shell loading.

Here was an enterprise that involved a government investment of hundreds of millions of dollars in plant facilities alone, and in addition swept into its train a large part of the American steel industry and nearly all the large American explosives industry. It should be remembered, too, that this vast machine was put together and constructed after the sum-

mer of 1917 was at hand, for the whole system was predicated upon agreements made with the Allies in the summer and autumn of 1917. Between that time and the date of the armistice the ammunition industry was set up, the plans for its operation were laid out, and the industry brought forth a finished product that reached France and struck the enemy. And behind these first exportations of American ammunition the machine was grinding out a weight of *matériel* whose overwhelming mass was already in sight.

The American ammunition program has sometimes been criticized as a failure. In the light of the above facts, it is submitted that, far from being a failure, the production of ammunition viewed as a whole was one of the signal industrial accomplishments of the war.

Artillery

Calibers for pedition.
75-mm. gun]
75-mm. gun
75-mm. gun
75-mm. A. A.
3-inch A. A.
4.7-inch gun
4.7-inch gun
5-inch S. C. g
6-inch S. C. g
155-mm. gun
155-mm. howi
155-mm. shra
8-inch howitz
9.2-inch howit
240-mm. howi
8-inch S. C. g
10-inch S. C.
Total .
Calibers for State.
2.95-inch m H. E. .
2.95-inch m shrapnel
3-inch F. G.
3-inch F. G.
3.8-inch howit
3.8-inch howi
4.7-inch howit
4.7-inch howi
6-inch howitz
6-inch howitz
Total .
Grand to

CHAPTER IX

TANKS

THE tank, more than any other weapon born of the World War, may be called the joint enterprise of the three principal powers arrayed against Germany—America, France, and Great Britain. An American produced the fundamental invention, the caterpillar traction device, which enabled the fortress to move. A Frenchman took the idea from this and evolved the tank as an engine of war. The British first used the terrifying monster in actual fighting.

There is a common impression throughout America that the British Army invented the tank. The impression is wrong in two ways. The French Government awarded the ribbon of the Legion of Honor to the French ordnance officer who is officially hailed as the tank's inventor. His right to the honor, however, was disputed by a French civilian who possessed an impressive exhibition of drawings to prove that he and not the officer was the inventor. Wherever the credit for the invention belongs, the French were first to build tanks, building them only experimentally, however, and not using them until after the British had demonstrated their effectiveness. In the second place, it was not the British Army which adopted them first in England, but the British Navy. The tank as an idea shared the experience of many another war invention in being skeptically received by the conservative experts. The British Navy, indeed, produced the first tanks in England.

But to the British Army goes the glory of having first used them in actual fighting and of establishing them in the forefront of modern offensive weapons. Brought forth as a surprise, the tanks made an effective début in the great British

drive for Cambrai. Later the enemy affected to scoff at their usefulness. The closing months of the tanks' brief history, however, found them in greater favor than ever, and they were used by both sides in increasing numbers.

Up to the beginning of the summer of 1917 there was little accurate information in this country regarding the tanks. Somewhat hazy specifications then began to come from Europe about the designs of the different tanks at that particular time in use on the battle front, but these specifications were exceedingly rough and sketchy, consisting in the main merely of the facts that the machines should be able to cross trenches about six feet wide, that each should carry one heavy gun and two or three machine guns, and that their protection should consist of armor plate about five-eighths of an inch thick.

During that first war summer the Ordnance Department started to build two experimental tanks. The production officers designed the experimental models, not to show fighting ability, but to test various methods of propulsion. It was desired to apply to them the caterpillar traction device specially articulated with large wheels on which the caterpillar belt was to run. This combination of wheels and belt was then being used in the designs for artillery tractor mounts and pullers. We also wished to test in the tanks the comparative possibilities of gasoline and steam propulsion.

Meanwhile ordnance officers with the A. E. F. were making a thorough, if somewhat protracted, study of tanks. Early in the summer Lieutenant Colonel James A. Drain, an emergency officer, had crossed to France, where he became ordnance officer of the First Division. Colonel Drain soon became an enthusiast for tanks. The war had become a question of which side could kill the most men, and therefore it called for killing machinery. It seemed to Colonel Drain that the tank was the most efficient of such machines. After Cambrai the British held it an axiom that an army with tanks could make twice the distance at half the cost in human life that one unsupported by tanks could make. Given enough tanks, the American forces could go steadily through to Berlin, in Colonel Drain's opinion,

and he urged that the Ordnance Department at home go in for heavy production.

In October, 1917, the Commander of the A. E. F. directed Colonel Drain and Colonel Herbert W. Alden, a temporary officer who in civilian life had been an engineer for the Timken Axle Company of Detroit, to confer with the British and in three weeks report a plan for American tank construction. The two officers found the British and French armies developing their separate tank equipments without relation to each other. The British were wedded to the heavy tank, but were experimenting and developing a light tank. The French, on the other hand, had developed the light 6-ton, 2-man Renault and were devoted to it, but were experimenting with a heavy tank. The result of the conferences with the Americans was a tripartite agreement that the tank programs of the three armies were to be coördinated and that all three nations were to contribute to the construction of tanks.

As to the light tank, there was no questioning the superiority of the Renault. It was also understood that this was a machine which might be built to advantage in the factories of the United States. The contribution of the French, therefore, to the combined program consisted of their secret plans and drawings of the Renault tank. These the French authorities turned over to the United States.

The plans and samples of the Renault tank reached the United States in December, 1917, accompanied by a French engineer prepared to help us get our 6-ton tank manufacture under way. The drawings, being in the metric system, had to be translated to the English measures system to accommodate American shop practice and equipment, a task that took time. It was also necessary to do some redesigning, although not enough was done to suit the American manufacturers. Because of the unusualness of the design and the difficulties involved in the manufacture, it was hard to find American concerns willing to go into the enterprise. There were no companies in the United States equipped to turn out the armor for the French tank as it was specified, for the French made no

attempt to adhere to simple shapes in the plates required. The Department had to build up a new factory source of supply of plates of this sort.

The difficulties were eventually solved by parceling out the manufacture of parts to many concerns and designating three factories as assembling plants. The Maxwell Motors Company and the C. L. Best Company, both of Dayton, and the Van Dorn Iron Works of Cleveland, assembled the Renault tanks and also manufactured some of the integral parts. More than twenty other American manufacturers built parts for the machine.

The contracts called for the delivery of 4,440 Renault tanks, each to cost the Government about $11,500. Although the manufacturers did not get at the job until the winter was well advanced, they started to turn out finished machines in October, 1918, and before the armistice was signed had delivered sixty-four. At that time the production was expanding at a rate to leave little doubt that the Renault program would have been successfully completed by April, 1919.

The French Renault not being adapted to American methods of mass production, the ordnance department designers undertook to modify it with practical manufacturing considerations in mind. The result was what was virtually a new tank and one typically American. Our officers regarded it as a distinct improvement on the French machine. It was easier to build; it weighed no more than the French machine, yet cost considerably less; and it was a more powerful fighter, for it carried three men instead of two and mounted two guns, one a machine gun and the other a 37-millimeter gun. In justice to the original Renaults, however, it must be stated that a few of them also carried 37-millimeter guns. We ordered 1,000 of these Mark I tanks, as they were called, but the armistice cut short the manufacturing operation in its infancy.

Meanwhile, during the summer of 1918 our tank program was enriched by the development of a 3-ton, 2-man tank originated by the Ford Motor Company. This was much the smallest tank ever built, and it cost only about $4,000. The Ford

Photo from Ordnance Department

RENAULT-TYPE 6-TON TANK

Photo from Ordnance Department

AMERICAN MARK VIII TANK FORDING STREAM

From a photograph lent by R. E. Carlson

THE ANGLO-AMERICAN TANK COMMISSION

Seated at the left is Colonel Sir Albert G. Stern, the British Commissioner. At his left, also seated, is Colonel James A. Drain, the American Commissioner.

tank mounted a machine gun and could skim (relatively speaking) over the ground at eight miles an hour. Great things were expected of this implement. The War Department plunged into the production, ordering over 15,000 as a preliminary. The Ford Company, with its well-known methods of production, expected to turn them out at the rate of a hundred a day after January 1, 1919. The company built fifteen before the armistice, of which ten were sent to France for test in the field.

The construction of big tanks was a different proposition. The British were by no means satisfied with their large tank, and it was decided to create an entirely new design. An Anglo-American tank commission was formed with Colonels Drain and Alden as the American members. The chief designers of the new tank, the Anglo-American Mark VIII, as it was later styled, were Colonel Alden and Colonel Sir Albert G. Stern, K. C. B., C. M. G. It was decided to erect the assembling factory in France, where a site was granted by the French Government and workmen were supplied for its construction. England had been building tanks since 1915 and had developed a suitable armor plate. The English also possessed guns adapted for use in big tanks. The plan, therefore, was that the British should supply armored hulls, guns, and ammunition, while we should furnish engines, traction mechanisms, and electrical equipments. An interesting point in connection with this agreement was that it was not military at all: it took the form of an actual treaty with Great Britain, signed by Ambassador Page in behalf of the United States.

As soon as the agreement was signed the project went forward. Ground was broken for the assembling plant in France. The British Government placed contracts for the production of the British components, and Colonel Alden returned to take charge of the work in the United States. Each complete tank was to cost about $35,000. The cost of the American components was about $15,000. The American contracts went to seventy-two manufacturers. The greater part of the manufacturing had been done when the armistice was signed, and

on that day the first Mark VIII tank was undergoing its trials. The whole project was abandoned after the armistice.

The trials of the pilot Anglo-American tank, as it was called, proved it to be not only a complete success, but one of the most formidable engines of war ever produced. It was a veritable dreadnought of the land. It weighed thirty-five tons, and it was as large a machine as could travel on a flat car within the French railway tunnel and platform clearances. It was manned by an officer and a crew of ten men. The officer sat in the conning tower and directed his men through an interphone system similar to that used in airplanes. The armament consisted of seven machine guns and two 6-pounders, British naval guns. One of the machine guns was mounted in the turret to harass low-flying airplanes. The monster was immune to damage from ordinary projectiles. Originally we had thought that a tank ought to be able to cross a 6-foot trench. The Mark VIII could step across a trench sixteen feet wide as if it did not exist.

The original big tank carried propulsion engines and gun crews in the unpartitioned hull. A shell that penetrated the armor and wrecked the gasoline tanks instantly turned the interior of the tank into an inferno from which no man escaped alive. In the Mark VIII the gunners worked in a room separated from the engine room by a steel bulkhead. Mechanical ventilation took in fresh air from the top and exhausted engine and gun fumes through the ports. The side turrets for the big guns swung inward to permit the tank to be compressed to the width of a freight car. The tank carried a wireless equipment. Its great weight was so distributed on the traction belts that the ground pressure under the caterpillars was but seven and one-half pounds to the square inch, about the pressure exerted by the foot of a man. Thus it could cross any ground on which a man could walk, and it could make six miles an hour.

It was estimated that each Mark VIII tank would have the offensive strength of 1,000 soldiers and an even greater defensive strength. The Anglo-American project called for the

delivery of 1,500 of them—the offensive equivalent of 1,500,000 soldiers, more fighting men than there were in the A. E. F. at the time of the armistice.

Even this equipment did not satisfy the Ordnance Department, and after the Anglo-American project was well under way we set out to duplicate the production on our own, making not only motors and caterpillars, but armored hulls and guns as well. The orders called for the delivery of 1,450 all-American 35-ton tanks of the international design. The total big-tank program, therefore, if it had been carried out, would have placed on the western front the mechanical equivalent of nearly 3,000,000 troops.

The manufacture of the all-American Mark VIII was just getting started at the time of the armistice. Thereafter the orders were cut down until they provided for the completion of only 100 tanks of this design, all of which were delivered later to the War Department.

In the summer of 1918 the production of components for the 35-ton tanks was not going ahead satisfactorily, and the War Department secured Mr. Louis J. Horowitz, of the Thompson-Starrett Company, as director of tank production. His presence at the head of the enterprise had an immediate effect in speeding up the manufacture.

In all the Government obligated itself to pay out $175,000,000 for tanks. This figure included the cost of expanding the facilities at various factories that took contracts.

Tanks

	Number ordered	*Number accepted to Nov. 11, 1918*	*Total number accepted*	*Floated to Nov. 11, 1918*
3-ton	15,015	15	15	10
6-ton	4,440	64	950	6
Anglo-American Mark VIII	1,500	1	1	..
American Mark VIII	1,450	..	100	..

CHAPTER X

MACHINE GUNS

THE machine gun is typically and historically an American device. An American invented the first real machine gun ever produced. Another American, who had taken British citizenship, produced the first weapon of this type that could be called a success in war. Still a third American gave to the Allies at the beginning of the World War a machine gun which revolutionized the world's conception of what that weapon might be; and a fourth American inventor, backed by our Ordnance Department, enabled the American forces to take into the field in France what was probably the most efficient machine gun ever put into action.

The machine gun as an idea is not modern at all. The idea behind it has been engaging the attention of inventors for several centuries. This idea was inherent in guns which existed in the seventeenth and eighteenth centuries; but these should be called rapid-fire guns rather than machine guns, since no machine principle entered into their construction. They usually consisted of several gun barrels bound together and fired simultaneously.

The first true machine gun was the invention of Richard Jordan Gatling, an American, who in 1861 brought out what might be termed a revolving rifle. The barrels, from four to ten in number, were placed parallel to each other and arranged on a common axis about which they revolved in such a manner that each barrel was brought in succession into the firing position. This gun was used to some extent in our Civil War and later in the Franco-Prussian War.

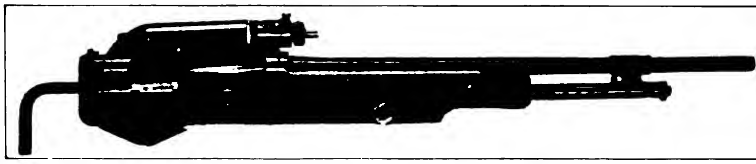
In 1866 Reffye, a French inventor, brought out the first mitrailleuse—a mounted machine gun of the Gatling type, drawn by four horses. It had twenty-five rifled barrels and

Photo from Ordnance Department

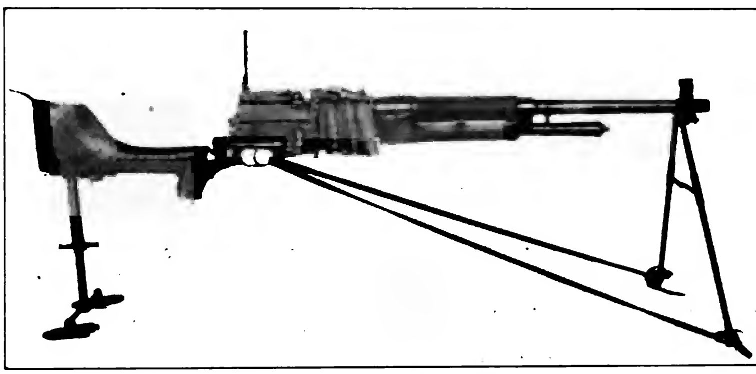
AMERICAN MARK VIII TANK TOPPING A HILL

Photo from Ordnance Department

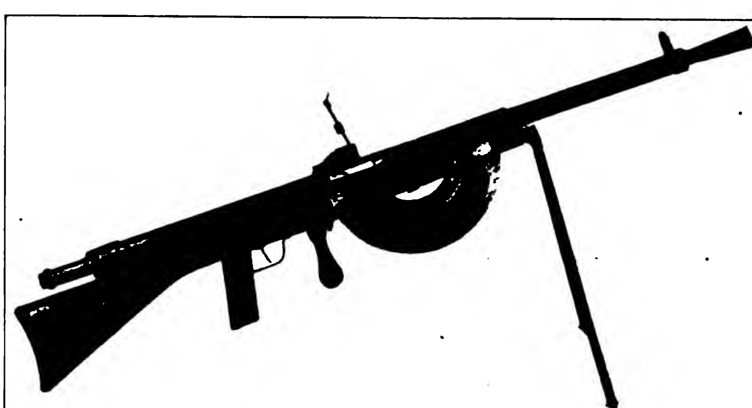
ASSEMBLING MARK VIII TANKS IN ROCK ISLAND ARSENAL



MARLIN SYNCHRONIZED AIRCRAFT GUN



BENÉT-MERCIÉ MACHINE RIFLE



Photos from Ordnance Department

CHAUCHAT AUTOMATIC RIFLE

could fire 125 shots a minute. The weapon, however, during the Franco-Prussian War, turned out to be a failure, for the reason that it proved an excellent target for the enemy's artillery and was not sufficiently mobile. Accordingly the French Government abandoned it.

Sir Hiram S. Maxim, who was American born, in 1884 developed a machine gun which operated automatically by utilizing the force of the recoil. This gun was perfected and became a serviceable weapon for the British Army in the Boer War. The Maxim gun barrel was cooled by the water-jacket system. When the water became hot it exhausted a jet of steam which could be seen for long distances across the South African veldt, making it a mark for the Boer sharpshooters. This defect was remedied in homemade fashion by carrying the exhaust steam through a hose into a bucket of water, where it was condensed. This Maxim gun fired 500 shots a minute.

Meanwhile the Gatling gun had been so improved in this country that it became one of our standard weapons in the Spanish-American War. Later on it was used in the Russo-Japanese War.

The Colt machine gun also existed in 1898. This was the invention of John M. Browning, whose name has been prominently associated with the development of automatic firearms for the last quarter of a century.

In England the Maxim gun was taken up by the Vickers Company, eventually becoming what is known to-day as the Vickers gun. In 1903 or 1904 the American Government bought some Maxim machine guns which were then being manufactured by Colt's Patent Firearms Manufacturing Company, at Hartford, Connecticut.

In no war previous to the one concluded in 1918 did the machine gun take a prominent place in the armaments of contending forces. The popularity of the earlier machine guns was retarded by their great weight. Some of them were so heavy that it took several men to lift them. Throughout the history of the development of machine guns the tendency has been toward lighter weapons, but it was not until the World War that serv-

iceable machine guns were made light enough to give them great effectiveness and popularity. Such intense heat is developed by the rapid fire of a machine gun that unless the barrel can be kept cool the gun will soon refuse to function. The water jacket which keeps the gun cool proved to be the principal handicap to the inventors who were trying to remove weight from the device. The earliest air-cooled guns were generally unsuccessful, for the firing of a few rounds would make the barrels so hot that the cartridges would explode spontaneously in the chamber, thus rendering the weapons unsafe. The Benét-Mercié partly overcame this difficulty by having interchangeable barrels. As soon as one barrel became hot it could be quickly removed and its cool alternate inserted in its place.

These conditions led to two separate developments—the heavy type machine gun, which must be capable of long-sustained fire, and the automatic rifle, whose primary requisite is extreme lightness. These requirements ultimately brought about the elimination from ground use, in France and in the United States, of guns of the so-called intermediate weight, as incapable of fulfilling to the fullest degree either of the above requirements.

The machine gun produced by the American inventor, Colonel I. N. Lewis, was a revelation when it came to the aid of the Allies early in the World War. This was an air-cooled gun which could be fired for a considerable time without excessive heating, and it weighed only twenty-five pounds, no great burden for a soldier. The Lewis machine gun was hailed by many as the greatest invention brought into prominence by the war, although its weight put it in the intermediate class, with limitations as noted above.

Along in the first decade of the present century the Benét-Mercié automatic machine rifle was developed. This was an air-cooled gun of the automatic rifle type and weighed thirty pounds. Light as this gun was, it was still too heavy to be of great service as an automatic rifle, for even a strong man would soon tire of holding thirty pounds up to his shoulder; and it was therefore in the intermediate class.

The Germans had apparently realized better than anyone else the value of machine guns in the kind of fighting which they expected to be engaged in; and they supplied them to their troops in greater numbers than the other powers did, having, an early report stated, 50,000 Maxim machine guns at the outbreak of hostilities. The Austrian Army had adopted an excellent heavy-type machine gun known as the Schwarzlose, the chief feature of which lay in the fact that it operated with only one major spring.

Such, although incompletely set forth here, was the machine gun situation at the beginning of the World War. The nations, with the exception of Germany, had been slow to promote machine gunnery as a conspicuous phase of their military preparedness. In our Army we had a provisional machine gun organization, but no special officers and few enthusiasts for machine guns. We were content with a theoretical equipment of four machine guns to the regiment. The fact was that in no previous war had the machine gun demonstrated its tactical value. The chief utility of the weapon was supposed to lie in its police effectiveness in putting down mobs and civil disorders and in its value in other special situations, particularly defensive ones.

The three years of fighting in Europe before the United States was drawn in had demonstrated the highly important place which the machine gun held in modern tactics. Because of the danger of our position we had investigated many phases of armed preparedness, and in this investigation numerous questions had arisen regarding machine guns. The Secretary of War had appointed a board of seven army, navy, and marine officers and two civilians to study the machine gun subject, to recommend the types of guns to be adopted, the number of guns we should have to the unit of troops, how these guns should be transported, and other matters pertaining to the subject. Six months before we declared war this board submitted a report strongly recommending the previously adopted Vickers machine gun and the immediate procurement of 4,600 such guns. In December, 1916, the War Department acted on

this report by contracting for 4,000 Vickers machine guns from the Colt's Company, in addition to 125 previously ordered.

The Vickers gun belongs to what is known as the heavy type of machine gun. The board found that the tests it had witnessed did not then warrant the adoption of a light type machine gun, although the Lewis gun, of the intermediate type, was then being manufactured in this country. The board, however, recommended that we conduct further competitive tests of machine guns at the Springfield Armory, in Massachusetts, these tests to begin May 1, 1917, the interval being given to permit inventors and manufacturers to prepare equipment for the competition.

The war came to us before these tests were made. On the 6th day of April, 1917, our equipment included 670 Benét-Mercié machine rifles, 282 Maxim machine guns of the 1904 model, 353 Lewis machine guns, and 148 Colt machine guns. The Lewis guns, however, were chambered for the .303 British ammunition and would not take our service cartridges.

The manufacturing facilities for machine guns in this country were much more limited in extent than the public had any notion of. Both England and France had depended mainly upon their own manufacturing facilities for their machine guns, the weapons which they secured on order from the United States being supplementary and subsidiary to their own supplies. We had at the outbreak of the war only two factories in the United States which were actually producing machine guns in any quantity at all. These were the Savage Arms Corporation, which in its factory at Utica, New York, was nearing the completion of an order for about 12,500 Lewis guns for the British and Canadian governments, and the Marlin-Rockwell Corporation, which had manufactured a large number of Colt machine guns of the old lever type for the Russian Government. In the spring of 1917 the Colt factory was equipping itself with machinery to produce the 4,125 Vickers guns, the order for 4,000 of which had been placed the previous December by the War Department on recommendation of the

machine gun board. None of these guns, however, had been completed when the United States entered the war. The Colt's Company also held a contract for Vickers guns to be produced for the Russian Government.

It was evident that we should have to build up in the United States almost a completely new capacity for the production of machine guns. Nevertheless, we took advantage of what facilities were at hand; and at once—in fact, within a week after the declaration of war—we began placing orders for machine guns. The first of these orders came on April 12, when we placed a contract with the Savage Arms Corporation for 1,300 Lewis guns; which, as manufactured by that corporation, had by this time been overhauled in design and much improved. This order was later heavily increased. On June 2 we placed an order with the Marlin-Rockwell Corporation for 2,500 Colt guns, these weapons to be used in the training of our machine gun units.

In this connection the reader should bear continually in mind that throughout the development of machine gun manufacture we fully utilized all existing facilities in addition to building up new sources of supply. In other words, whenever concerns were already engaged in the manufacture of machine guns, of whatever make or type, we did not stop the production of those types in such plants and convert the establishments into factories for making other weapons: we had them continue in the manufacture in which they were engaged, giving them orders which would enable them to expand their facilities in their particular fields of production. Then, when it became necessary for us to find factories to build Browning guns and some of the other weapons on which we specialized, we found entirely new capacity for this additional production. The first American division of troops, sent to France less than three months after the declaration of war, were necessarily armed with the machine guns already at hand, which were the Benét-Mercié machine rifles.

Meanwhile the development of machine guns in Europe had been going on at a rapid rate. The standard guns in use by

the French Army were now the Hotchkiss heavy machine gun and the Chauchat light automatic rifle, both effective weapons. Upon the arrival of our first American division in France the French Government expressed its willingness to arm this division with Hotchkiss and Chauchat guns; and thereafter the French facilities proved to be sufficient to equip our troops with these weapons until our own manufacture came up to requirements.

The 1st of May, 1917, inaugurated the tests recommended by the investigation board, these tests continuing throughout the month. To the competition were brought two newly developed weapons produced by the inventive genius of that veteran of small-arms manufacture, John M. Browning. Mr. Browning had been associated with the Army's development of automatic weapons for so many years that he was peculiarly fitted to produce a mechanism adaptable to the quantity production which our forthcoming effort demanded. Both the Browning heavy machine gun and the Browning light automatic rifle which were put through these tests in May had been designed with a view to enormous production quickly attained, and their simplicity of design was one of their chief merits. After the tests the board pronounced these weapons the most effective guns of their type known to the members. The Browning heavy gun with its water jacket filled weighed 36.75 pounds, and the Browning automatic rifle weighed only 15.5 pounds. These May tests also proved the Lewis machine gun to be highly efficient. The board recommended the production of large numbers of all three weapons. The board also approved the Vickers gun, which weighed 37.5 pounds, and we accordingly continued it in manufacture.

The first act of the Ordnance Department after this report had been received was to increase greatly the orders for Lewis machine guns with the Savage Arms Corporation, and its second was to make preparation for an enormous manufacture of Browning machine guns and Browning automatic rifles. Mr. Browning had developed these weapons at the plant of the Colt's Patent Firearms Manufacturing Company, of Hart-

ford, Connecticut, which concern owned the exclusive rights to both these weapons under the Browning patents. This company at once began the development of manufacturing facilities for the production of Browning guns. In July, 1917, orders for 10,000 Browning machine guns and 12,000 Browning automatic rifles were placed with the Colt's Company. It should be remembered that the Colt's Company was in the midst of preparations for the production of large numbers of Vickers machine guns; and the Government required that the Browning manufacture be carried on without interference with the existing contracts for Vickers guns. This requirement necessitated an enormous expansion of the Colt's plant to take care of its growing contracts for Browning guns. This concern prepared to make the Browning automatic rifle, the lighter gun, at a new factory at Meriden, Connecticut.

In its arrangements with the Colt's Company the Government recognized that its future demands for Browning guns would be far beyond the capacity of this one concern to supply. Consequently, for a royalty consideration, the Colt's Company surrendered for the duration of the war its exclusive rights to manufacture these weapons, an arrangement approved by the Council of National Defense. Mr. Browning, the inventor of the guns, was also compensated by the Government for weapons of his invention manufactured during the war. In the arrangement the Government acquired the right to manufacture during the period of the emergency all other inventions that might be developed by Mr. Browning—an important consideration, for at any time the inventor might add improvements to the original designs or bring out accessories that would add to the efficiency or effectiveness of the weapons. It should be added that throughout this period Mr. Browning's efforts were constantly directed toward the perfection of these guns and the development of new types of guns and accessories, and that his services in this field were of great value to the War Department.

When these necessary preliminary matters had been settled, the Ordnance Department made a survey of the manufacturing

facilities of the United States to determine what factories could best be set to work to produce Browning guns and rifles, always with special care that no existing war contracts, either for the Allies or for the United States, be disturbed. By September this survey was complete, and by this time we also had definite knowledge of the rate of enlargement of our military forces and their requirements for machine guns. We were ready to adopt the program of machine gun construction that would keep pace with our needs, no matter what numbers of troops we might equip for battle. As a foundation for the machine gun program, in September, 1917, we placed the following orders: 15,000 water-cooled Browning machine guns with the Remington Arms-Union Metallic Cartridge Company, of Bridgeport, Connecticut; 5,000 Browning aircraft machine guns with the Marlin-Rockwell Corporation, of New Haven, Connecticut; and 20,000 Browning automatic rifles with the Marlin-Rockwell Corporation. In this connection it should be explained that the Browning aircraft gun is essentially the heavy Browning with the water jacket removed. It was practicable to use it thus stripped, because in aircraft fighting a machine gun is fired, not continuously, but only at intervals, and then only in bursts of fire too brief to heat a gun beyond the functioning point.

At the same time when these orders were placed, the Winchester Repeating Arms Company, of New Haven, Connecticut, was instructed to begin its preliminary work looking to the manufacture of Browning automatic rifles; and less than a month later, in October, an order for 25,000 of these weapons was placed with this concern. Then followed in December an additional order for 10,000 Browning aircraft guns to be manufactured by the Marlin-Rockwell Corporation. A contract for Browning aircraft guns was also given to the Remington Arms-Union Metallic Cartridge Company.

Before the year ended the enormous task of providing the special machinery for this practically new industry was well under way. The Hopkins & Allen factory, at Norwich, Connecticut, had previously been engaged upon a contract for mili-

tary rifles for the Belgian Government. Before this order was completed the Marlin-Rockwell Corporation took over the Hopkins & Allen plant and set it to producing parts for the light Browning automatic rifles. Even this factory, however, could not produce the parts in sufficient quantities for the Marlin-Rockwell order, and the latter concern accordingly acquired the Mayo radiator factory, at New Haven, and equipped it with machine tools for the production of Browning automatic rifle parts. Such expansion was merely typical of what went on in the other concerns engaged in our machine gun production. Immense quantities of new machinery had to be built and set up in all these factories. But still the Ordnance Department kept on expanding the machine gun capacity. The New England Westinghouse Company, of Springfield, Massachusetts, in January, 1918, on its completion of a contract for rifles for the Russian Government, was at once given an order for Browning water-cooled guns. For reasons which will be explained later, the original order for Browning aircraft guns, which had been placed with the Remington Arms Company, was later transferred to the New England Westinghouse Company at their Springfield plant.

As soon as our officers in France could make an adequate study of our aircraft needs in machine guns, they discovered that in the three years of war only one weapon had met the requirements of the Allies for a fixed machine gun that could be synchronized to fire through the whirling blades of an airplane propeller. This was the Vickers gun, which was already being manufactured in some quantity in our country, and for which, three months before we entered the war, we had given an order amounting to 4,000 weapons. On the other hand, the fighting aircraft of Europe were also finding an increased need for machine guns of the flexible type—that is, guns mounted on universal pivots, which could be aimed and fired in any direction by the second man, or observer, in an airplane. The best gun we had for this purpose was the Lewis machine gun.

For technical reasons that need not be explained here, the

Vickers was a difficult gun to manufacture. The Colt's Company, which was producing these weapons, had been unable, in spite of their long experience in the manufacture of such arms and in spite of their utmost efforts, to deliver the finished Vickers guns on time, either to the Russian Government or to this country. But by expanding the facilities of this factory to the utmost, the concern achieved, by the month of May, a production of over fifty Vickers guns a day. Doubtless because of these same difficulties, neither the British nor the French Government had been able to procure Vickers guns as rapidly as they expanded the number of their fighting aircraft, and consequently when we entered the war we received at once a Macedonian cry from the Allies to aid in equipping the Allied aircraft with weapons of the Vickers type. An arrangement was readily reached in this matter. Our first troops in France needed machine guns for use on the lines. Our own factories had not yet begun the production of these weapons. Accordingly, in the fall of 1917 we arranged with the French high commissioner in this country to transfer 1,000 of our Vickers guns to the French air service, receiving in exchange French Hotchkiss machine guns for General Pershing's troops.

The demands of the Allied service had brought forth, we noted, only the Vickers machine gun as a satisfactorily synchronized weapon. But we, shortly after our entry into the war, had succeeded in developing two additional types of machine guns which gave every promise of being satisfactory for use as fixed synchronized guns on airplanes. One of these, of course, was the heavy Browning gun, stripped of its water jacket. Because this was a new weapon, requiring an entirely new factory equipment for its production, the day when Brownings would begin firing at the German battle planes was remote indeed, as time is reckoned in war. But our inventors had been improving a machine gun known as the Marlin, which was, basically, the old Colt machine gun, Mr. Browning's original invention, now of lighter construction and equipped with a piston firing action instead of a lever control. In the face of considerable criticism at the time, we proposed

to adapt this weapon to our aircraft needs as a stop-gap until Brownings were coming from the factory in satisfactory quantities. We took this course because we were prepared to turn out quantities of the Marlin guns in relatively quick time. As has been said, the Marlin resembled the Colt. The Marlin-Rockwell Corporation was already tooled up for a large production of Colt guns, and this machinery, with slight modifications, could be used to produce the Marlin.

We decided upon this course shortly after the declaration of war. Then followed a severe engineering and inventive task: the development of a high-speed hammer mechanism and a trigger motor which would adapt the gun for use with the synchronizing mechanism. But then occurred one of those surprising successes that sometimes bless the efforts of harassed and hurried executives, at their wits' end to meet the demand of some great emergency. The improvements added to the Marlin gun eventually transformed it in unforeseen fashion into an aircraft weapon of such efficiency that not only our own pilots, but those of the French air forces as well, were delighted with it. When it was proposed to adapt the Marlin gun for synchronized use on airplanes, the Ordnance Department detailed officers to coöperate with the Marlin company in its efforts. For technical reasons of design, the original gun apparently had little or no adaptability to such use. Many new models were built, only to be knocked to pieces after the failure of some unit to perform properly the work for which it was designed. Nevertheless the enthusiasm of the company for its project could not be chilled, and it continued the development until the gun finally became a triumph in gas-operated aircraft ordnance. In the latter part of August, when we were using the Marlin gun at the front, cablegram after cablegram told us of the surprisingly excellent performances of this weapon in actual service. It is sufficient here to quote two of these messages from General Pershing, the first dated February 23, 1918:

Marlin aircraft guns have been fired successfully on four trips 13,000, 15,000 feet altitude, and at temperature of minus 20 degrees F.

On one trip guns were completely covered ice. Both metallic links and fabric belts proved satisfactory.

(Cartridges were usually fed into the fixed aircraft guns, inserted in belts made of metallic links which disintegrated as the guns were fired.) On November 2, 1918, just before the armistice was signed, General Pershing cabled as follows, in part:

Marlin guns now rank as high as any with pilots, and are entirely satisfactory.

The French Government tested the Marlin guns and declared them to be the equal of the Vickers. In order to meet the ever-increasing demands of the Air Service for machine guns capable of synchronization, the original order for 23,000 Marlin guns, placed in September, 1917, with the Marlin-Rockwell Corporation, was afterwards increased to 38,000. Along in 1918 the French tried to procure Marlins from this country, but by that time the Browning production was reaching great proportions, and the equipment at the Marlin plant was being altered to make Brownings.

The original order for Lewis guns, placed with the Savage Arms Corporation, had contemplated their use by our troops in the line; but when it became evident that the available manufacturing capacity of the United States would be strained to the utmost to provide enough guns for our airplanes, we diverted the large orders for Lewis guns entirely to the Air Service. This action was confirmed by cabled instructions from General Pershing. To the flexible aircraft work the weapon was admirably adapted.

To the machine gun tests of May, 1917, the producers of the Lewis gun brought an improved model, chambered for our own standard .30-caliber cartridges, instead of for the British .303 ammunition, with some fifteen modifications in design in addition to those which had been presented to us before, and some added improvements in construction and in the metallurgical composition of the materials. From our point of view, this new model Lewis was a greatly improved weapon. (The fact should be stated here that the Lewis gun, as so successfully

made for the British service by the Birmingham Small Arms Company, had never been procurable by the United States, even in a single sample for test.) The Lewis accordingly became the standard flexible gun for our airplanes. The Savage Arms Corporation was able to expand its facilities to fill every need of our Air Service for this type of weapon, and therefore we made no effort to carry the manufacture of Lewis guns into other plants. Before 1917 came to an end the Savage company was delivering the first guns of its orders.

During the difficulties on the Mexican border the United States secured from the Savage Arms Corporation several hundred Lewis guns made to use British ammunition. In order to be sure that the guns would be properly used, experts from the factory were sent out to instruct the troops who were to receive the guns. Ordnance officers also went out on this instruction work and established machine gun schools along the border. The troops did not find the guns entirely satisfactory, in spite of expert instruction by men from the factory. The trouble with the guns at this time was due to the fact that the company making them in the United States had been engaged in the manufacture of machine guns for a short time only and had run into several minor difficulties in the design and manufacture; difficulties which caused considerable trouble in operating the guns in the field, and which were subsequently corrected in the fifteen changes mentioned above. The machine gun schools which were established on the border taught the mechanism not only of the Lewis gun, but also of the other types of guns with which the various troops were armed. The first fact that these schools disclosed was that much of the trouble encountered in operating machine guns was due to our soldiers' unfamiliarity with the weapons. At that time we had few experts in the operation of any make of machine gun.

Soon after the establishment of machine gun schools on the border it became evident that the system of instruction devised by our ordnance officers had gone a long way toward overcoming the difficulties. The utility of these schools was so marked that on the outbreak of the war with Germany the

Ordnance Department established a machine gun school at Springfield Armory. The first class of this school consisted of a large number of technical graduates from the Massachusetts Institute of Technology and other such schools. These men, employed as civilians, were taught the mechanism of machine guns theoretically in as thorough a manner as possible, and were also given an opportunity to fire the guns and find out for themselves just what troubles were likely to occur. Many of these men were afterwards commissioned as officers in the Ordnance Department and sent to the various cantonments throughout the United States to establish schools of instruction in the mechanism of the various machine guns.

After this class of civilians had been graduated from the Springfield school, a number of training-camp candidates were instructed and afterwards commissioned. When the full success of this school was realized, it was enlarged and expanded, and it instructed not only civilians and training-camp candidates, but also officers of the Ordnance Department, who were trained as armament officers, instructors, and the like. Later the school was still further expanded to include a large class of men enlisted for duty as armorers. In all, over 500 officers were instructed at the Springfield school. When hostilities ceased, the graduates of the Springfield Armory machine gun school were in almost every branch of endeavor connected with arms, ammunition, and kindred subjects.

Now, let us examine the first results of the early effort in machine gun production. Within a month after the first drafted troops reached their cantonments we were able to ship fifty Colt guns from the Marlin-Rockwell Corporation to each National Army camp, these guns to be used exclusively for training our machine gun units. Before another thirty days passed we had added to the machine gun equipment of each camp twenty Lewis guns of the ground type, and thirty Chauchat automatic rifles, bought from the French. (The Lewis ground gun was almost identical with the aircraft type, except that its barrel was surrounded by an aluminum heat radiator for cooling, a device not needed on the guns of airplanes be-

cause of the latter's shorter periods of fire.) Also, in the autumn of 1917 we were able to issue to each National Guard camp a training equipment consisting of thirty Colt machine guns, thirty Chauchat automatic rifles, and from fifty to seventy Lewis ground guns.

At the beginning of 1918 our machine gun manufacture was well under way. Here was the industrial situation at this time: The Savage Arms Corporation was producing Lewis aircraft machine guns of the flexible type; the Marlin-Rockwell Corporation was manufacturing large quantities of Marlin aircraft machine guns of the synchronizing type; the Colt's Patent Firearms Manufacturing Company was building Vickers machine guns of the heavy mobile type; and a number of great factories were tooling up at top speed for the immense production of Browning guns of all types soon to begin. Meanwhile we kept increasing our orders as rapidly as conditions warranted.

By May, 1918, the first twelve divisions of American troops had reached France. They were all equipped with Hotchkiss heavy machine guns and Chauchat automatic rifles—both kinds supplied by the French Government. During May and June, eleven American divisions sailed, and the heavy machine gun equipment of these troops, consisting of Vickers guns, was American built. For their light machine guns these eleven divisions received the French Chauchat rifles in France. After June, 1918, all American troops to sail were supplied with a full equipment of Browning guns, of both the light and the heavy types. Part of these Brownings were issued to the troops before they sailed, and the rest upon their arrival in France.

The Savage Arms Corporation built about 3,500 Lewis guns of the ground type before diverting their manufacture to the aircraft type exclusively. By the end of July, 1918, the company had turned out 17,000 Lewis aircraft guns, not to mention 6,000 of the same sort which it had built and supplied to the American Navy. On the date of the armistice approximately 32,000 of these guns had been completed.

By the first of May, 1918, the Marlin-Rockwell Corporation had turned out nearly 17,000 Marlin aircraft guns with the synchronizing appliances. Thirty days later its total had reached 23,000. On October 1 the entire order of 38,000 Marlin guns had been completed, and the company began the work of converting its plant into a Browning factory.

On May 1, 1918, the Colt's Company had delivered more than 6,000 Vickers guns of the ground type. Before the end of July this output totaled 8,000, besides 3,000 Vickers guns which were later converted to aircraft use. In addition the Colt's Company had undertaken another machine gun project, of which nothing has been said hereinbefore. This concern had completed the manufacture of about 1,000 Vickers guns for the Russian Government. At this time the aviators at the front began using machine guns of large caliber, principally against observation balloons and dirigibles. The Allies had developed for this purpose an 11-millimeter Vickers machine gun, which means a gun with a bore diameter of nearly a half inch. The Ordnance Department undertook to change these Russian Vickers guns into 11-millimeter aircraft machine guns. This undertaking was successfully carried through by the Colt's Company, which delivered the first modified weapon in July and had increased its deliveries to a total of 800 guns by November 11, 1918. When the fighting ceased the Colt's Company had delivered 12,000 heavy Vickers guns and nearly 1,000 of the aircraft type. As was mentioned before, a considerable quantity of Vickers ground guns had been subsequently converted to aircraft use. The production of ground type Vickers ceased on September 12, 1918, by which date the manufacture of Browning guns had developed sufficiently to meet all our future needs. Thereafter the Colt's plant produced the aircraft types of Vickers guns only. We shipped 6,309 Vickers ground guns overseas before the armistice was signed, besides equipping six France-bound divisions of troops with these weapons in this country, making a total of 7,653 American-built Vickers in the hands of the American Expeditionary Forces. Later, we planned to replace these weapons

with Brownings, turning over the Vickers guns to the Air Service.

America's greatest feat in machine gun production was the development of the Browning weapons. These, as has been noted, were of three types: the heavy Browning water-cooled gun, weighing 37 pounds, for the use of our troops in the field; the light Browning automatic rifle, weighing 15.5 pounds, and in appearance similar to the ordinary service rifle, also for the use of our soldiers fighting on the ground; and, finally, the Browning synchronized aircraft gun of the rigid type, which was the Browning heavy machine gun made lighter by the elimination of its water jacket, speeded up to double the rate of fire, and provided with the additional attachment of the synchronized firing mechanism. Let us trace separately the expansion of the facilities for manufacturing these types.

In the first place, the Colt's Company, which owned the Browning rights, turned over to the Winchester Repeating Arms Company, in September, 1917, the task of developing the drawings and gauges for the manufacture of Browning automatic rifles on a large scale. The latter concern executed this work splendidly. Early in March, 1918, the Winchester Company had tooled up its plant and turned out the first Browning rifles. These were shipped to Washington and demonstrated in the hands of gunners before a distinguished audience of officers and other government officials, and their great success assured the country that America had an automatic rifle worthy of her inventive and manufacturing prestige. By the first of May the Winchester Company had turned out 1,200 Browning rifles.

The Marlin-Rockwell Corporation attained its first production of Browning rifles in June, 1918, by which time the Winchester Company had built about 4,000 of them. Before the end of June the Colt's Company added its first few hundreds of Browning rifles to the expanding output. By the end of July the total production of Browning rifles had reached 17,000, produced as follows: 9,700 by Winchester; 5,650

by Marlin-Rockwell; and 1,650 by Colt's. Two months later this total had been doubled—the exact figure being 34,500 Browning rifles—and on November 11, 1918, when the flag fell on this industrial race, the Government had accepted 52,238 light Browning rifles. Of these the Winchester Company had built, in round numbers, 27,000; Marlin-Rockwell, 16,000; and Colt's, 9,000.

But these figures give only an indication of the Browning rifle program as it had expanded up to the time hostilities ceased. When the armistice was signed our orders for these guns called for a production of 288,174, and still further large orders were about to be placed. As an illustration of the size which this manufacture would have attained, we had completed negotiations with one concern whereby its factory capacity was to be increased to produce, by June of 1919, 800 Browning rifles every twenty-four hours. After the armistice was signed we canceled orders calling for the manufacture of 186,000 Browning automatic rifles.

Of the 48,082 of these weapons sent overseas, 38,860 went in bulk on supply transports. The rest constituted the equipment of twelve divisions which carried their automatic rifles with them.

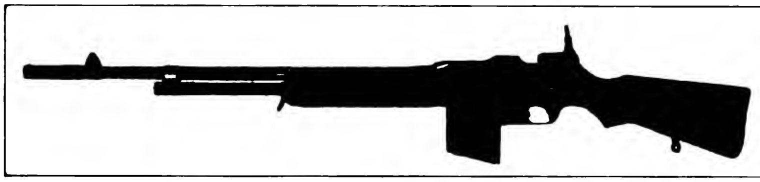
The Colt's Company itself developed the drawings and gauges for the quantity manufacture of the Browning gun of the ground type. It will be remembered that the New England Westinghouse Company was the first outside concern to begin the manufacture of these weapons. It received its orders in January, 1918. Within four months it had turned out its first completed guns, being the first company to deliver these weapons to the Government. By the first of May it had delivered eighty-five heavy Brownings. By the middle of May the Remington Company came into production of the heavy Brownings. The Colt's Company, which was required to continue its production of Vickers guns, was also retarded by the duty of preparing the drawings for the other concerns who had contracted to make heavy Brownings; and this factory, the birthplace of the Browning gun, was not able to produce any

Photo from Ordnance Department

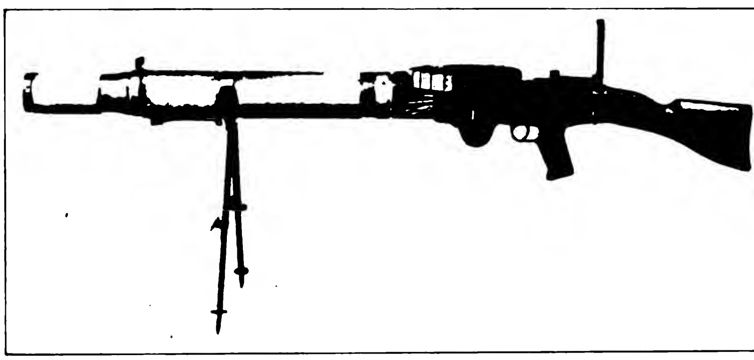
THE BROWNING HEAVY MACHINE GUN

Photo from Crown Cork & Seal Company

ASSEMBLING TRIPODS FOR BROWNING MACHINE GUNS



BROWNING LIGHT AUTOMATIC RIFLE



LEWIS MACHINE GUN, GROUND TYPE

Photos from Ordnance Department

HOTCHKISS HEAVY MACHINE GUN

until the end of June. By this time the Westinghouse Company had turned out more than 2,500 heavy Brownings, and Remington over 1,600. By the end of July the production of Browning machine guns at all plants had reached the total of 10,000; and two months later 26,000 heavy Brownings were in the hands of the Government. In the following six weeks this production was enormously increased, the total receipts by the Government up to November 11 amounting to about 42,000 heavy Browning guns. In round numbers Westinghouse produced 30,000 of these, Remington 11,000, and Colt's about 1,000. We shipped, in all, 30,582 heavy Brownings to the American Expeditionary Forces, 27,894 going on supply ships and the rest in the hands of twelve divisions of troops.

These shipments actually put in France, before the armistice was signed, enough heavy Brownings to equip completely all the American troops on French soil. But when these supplies were arriving the fight against the retreating German Army was at its hottest, and there was no time for the troops on the line to exchange their British-built and French-built machine guns for Brownings or to replace their Chauchat automatic rifles with light Brownings, of which there was also an ample supply in France. A report of the Chief Ordnance Officer, American Expeditionary Forces, as of February 15, 1919, shows that, except for anti-aircraft use, the Vickers and Hotchkiss machine guns with our troops had been almost entirely replaced by heavy Brownings, and that the Chauchat automatic rifles had been replaced by light Brownings.

When the armistice was signed we had placed orders for 110,000 heavy Brownings and were contemplating still further orders. We later reduced these orders by 37,500 guns.

Because the Marlin aircraft gun had performed so satisfactorily, and because our facilities for the manufacture of this weapon were large, the production of the Browning aircraft guns had not been pushed to the limit. Had it been, it would have interfered with the production of the Marlin gun at a time when it was most imperative to obtain an immediate

supply of fixed synchronized aircraft guns. Only a few hundred Browning aircraft guns had been completed before the close of the fighting. In its tests and performances this weapon had been speeded up to a rate of fire of from 1,000 to 1,300 shots a minute, which far surpassed the performances of any synchronized gun then in use on the western front.

By the spring of 1918 it became evident that we should require a special machine gun for use in our tanks. Several makes were considered for this purpose and finally discarded for one reason or another. The ultimate decision was to take 7,250 Marlin aircraft guns which were available and adapt them to tank service by the addition of sights, aluminum heat radiators, and handgrips and triggers. The rebuilding of these guns at the Marlin-Rockwell plant when the armistice was signed was progressing at a rate that ensured the adequate equipment of the first American-built tanks.

Meanwhile the Ordnance Department undertook the production of a Browning tank machine gun. This gun was developed by taking a heavy Browning water-cooled gun, eliminating the water jacket, substituting an air-cooled barrel of heavy construction, and adding handgrips and sights. The work was begun in September, 1918, and the completed model was delivered by the end of October. Before the armistice was signed five sample guns had been built, demonstrated at the Tank Corps training camps, and unanimously approved by officers of the Tank Corps designated to test it. After a test in France, their report stated: "The gun is by far the best weapon for tank use that is now known, and the Department is to be congratulated upon its development." An order for 40,000 Browning tank guns was given to the Westinghouse Company. This concern, already equipped for the manufacture of heavy Browning guns, was scheduled to start its deliveries in December, 1918, and to turn out 7,000 tank guns a month after January 1, 1919. After the signing of the armistice the order was cut down to approximately 1,800 guns.

After the entrance of the United States into the war the armies on both sides developed a new type of machine gun

fighting, which consisted in indirect firing, or laying down barrages of machine gun bullets. This required the development of tripods, clinometers for laying angles of elevation, and other special equipment; and speedy progress was being made in the quantity production of this *matériel* when the war came to an end.

In a complete machine gun program, not only must the guns themselves be built, but they must be fully equipped with tripods, extra magazines, carts for carrying both guns and ammunition, feed belts of various types, belt-loading machines, observation and fire control instruments, and numerous other accessories, the manufacture of which is absolutely essential, but usually unseen by the public. The extent of our work in accessories is indicated by a few approximate figures of deliveries up to the signing of the armistice: nonexpendable ammunition boxes, 1,000,000; expendable ammunition boxes, 7,000; expendable belts, 5,000; nonexpendable belts, 1,000,000; belt-loading machines, 25,000; water boxes, 110,000; machine gun carts, 17,000; ammunition carts, 15,000; tripods, 25,000.

The aircraft machine guns also required numerous accessories, some of them highly complicated in manufacture. This equipment consisted in part of special mounts for the guns, synchronizing attachments, metallic disintegrating link belts, electric heaters to keep the guns warm at the high altitudes of the aviator's battle field, and many other smaller items.

Not only our own forces, but the Allied armies as well, were enthusiastic about the Browning guns of both types, as soon as they had seen them in action. The best proof of this assertion is that in the summer of 1918 the British, Belgian, and French governments all made advances to us to ascertain the possibility of our producing Browning automatic rifles for their forces. On November 6, a few days before the end of hostilities, the French high commissioner requested that we supply 15,000 light Browning rifles to the French Army. We would not make this arrangement at the time, because we thought it inadvisable to divert any of our supplies of these

guns from our own troops until the spring of 1919, when we expected that our capacity for making light Brownings would exceed the demands of our own troops. Our demand for the lighter guns, incidentally, was far greater than we had originally expected. As soon as the Browning rifle was seen in action, the General Staff of our Expeditionary Forces at once increased by 50 per cent the number of automatic rifles assigned to each company of troops, and we were manufacturing to meet this augmented demand when the war ended. By spring of 1919 we expected to be furnishing light Brownings to the British and French armies as well as to our own.

Both types of Browning guns proved to be unqualified successes in actual battle, as numerous reports of our ordnance officers overseas indicated. The following report from an officer is typical of numerous other official descriptions of these weapons in battle use:

> The guns [heavy Brownings] went into the front line for the first time in the night of September 13. The sector was quiet and the guns were practically not used at all until the advance, starting September 26. In the action which followed, the guns were used on several occasions for overhead fire, one company firing 10,000 rounds per gun into a wood in which there were enemy machine-gun nests, at a range of 2,000 meters. Although the conditions were extremely unfavorable for machine guns on account of rain and mud, the guns performed well. Machine-gun officers reported that during the engagement the guns came up to the fullest expectations and, even though covered with rust and using muddy ammunition, they functioned whenever called upon to do so.
>
> After the division had been relieved, seventeen guns from one company were sent in for my inspection. One of these had been struck by shrapnel, which punctured the water jacket. All of the guns were completely coated with mud and rust on the outside, but the mechanism was fairly clean. Without touching them or cleaning them in any way, except to run a rod through the bore, a belt of 250 rounds was fired from each without a single stoppage of any kind.
>
> It can be concluded from the try-out in this division that the gun in its operation and functioning when handled by men in the field is a success.

The Browning automatic rifles were also highly praised by

our officers who had to use them. Although these guns received hard usage, being on the front for days at a time in the rain, when the gunners had little opportunity to clean them, they invariably functioned well.

On November 11 we had built 52,238 Browning automatic rifles in this country. We had bought 29,000 Chauchats from the French. Without providing replacement guns or reserves, this was a sufficient number to equip over a hundred divisions with 768 guns to the division. This meant light machine guns enough for a field army of 3,500,000 men. Of heavy machine guns we had at the signing of the armistice 3,340 of the Hotchkiss make, 9,237 Vickers, and 41,804 Brownings, or a total of 54,627 heavy machine guns—enough to equip the two hundred divisions of an army of 7,000,000 men, not figuring in reserve weapons. The daily maximum production of Browning rifles reached 706 before our manufacturing efforts were suddenly stopped, and that of Browning heavy machine guns 575. At the peak of our production a total of 1,794 machine guns and automatic rifles of all types was produced within a period of twenty-four hours. Our average monthly output for July, August, and September, 1918, was 27,270 machine guns and machine rifles of all types. The average monthly production of France was at this time 12,126 and that of Great Britain 10,947. Our total production between April 6, 1917, and November 11, 1918, was 181,662 machine guns and machine rifles, as against 229,238 by France and 181,404 by England in that same period.

One of the important contributions to the success of the machine gun program was the cordial spirit of coöperation which the War Department met from the machine gun manufacturers. Competitive commercial advantages weighed not at all against the national need, and the Department found itself possessed of a group of enthusiastic and loyal partners with whom it could attack the vast problem of machine gun supply. Without these partners and this spirit, the problem could not have been solved. The United States, starting almost from the zero point, developed in little more than a year a

machine gun production greater than that of any other country in the world, although some of the other countries had been fighting a desperate war for three years and building machine guns to the limit of their capacity.

machine gun production greater than that of any other coun-

CHAPTER XI

SERVICE RIFLES

IN the nineteen months of American belligerency we sent to France upward of two million soldiers. Each rifleman among them, as he stepped aboard his transport, carried his own gun. This weapon, which was to be his comrade and best friend in the perilous months to come, was an American rifle, a rifle at least the equal of any in use by soldiers of other nations, a rifle manufactured in an American plant. It may have been one of the dependable Springfield rifles. More likely, it was a modified 1917 Enfield, built from a design fundamentally British, but modified for greater efficiency by American ordnance officers after the actual entry of the United States into the great struggle. When it is considered that even a nation of such military genius as France, especially skilled as she was in the construction of military weapons, was three years in developing her full ordnance program, even though working at top speed, the rifle production of the United States stands out as one of the feats of the war.

The story of the modified 1917 Enfield, the rifle on which the American Expeditionary Forces based their chief dependence, is an inspiring chapter in our munitions history. It is a story of triumph over difficulties, of American productive genius at its best. To get this weapon, we temporarily forsook the most accurate army rifle the world had ever seen and straightway produced in great quantities another one, a new model, that proved itself to be almost, if not quite, as serviceable for the kind of warfare in which we were to engage.

America, since the days of Daniel Boone a nation of crack shots, was naturally the home of good rifles. Hence it is perhaps not surprising that the United States should have been

the nation to produce the most accurate military rifle known in its day. This was the United States rifle, model of 1903, popularly called the "Springfield." The Springfield rifle had superseded in our Army the Krag-Jörgensen, which we had used in the Spanish-American War. In that conflict the Spanish Army used a rifle of German design, the Mauser. Our ordnance officers at that time considered the Krag to be a more accurate weapon than the Mauser. Still, we were not satisfied with the Krag; and, after several years of development, in 1903 we brought out the Springfield, the most accurate and quickest-firing rifle that had ever come from an arsenal.

There was no questioning the superiority of the Springfield in point of accuracy. Time after time we pitted our army shooting teams against those of other nations and won the international competitions with the Springfield. We won the Olympic shoot of 1908 over England, Canada, France, Sweden, Norway, Greece, and Denmark. Again, in 1912, we won the Olympic shoot against England, Sweden, South Africa, France, Norway, Greece, Denmark, Russia, and Austria-Hungary. In 1912 the Springfield rifle, in the hands of Yankee marksmen, won the Pan-American match at Buenos Aires, and in 1913 it defeated Argentina, Canada, Sweden, and Peru. In all these matches the Mauser rifle was fired by various teams; but the Springfield never failed to defeat this German weapon, which it was to meet later in the fighting of the World War. Altogether, the Springfield rifle defeated the military rifles of fifteen nations in shooting competitions prior to the war, and in 1912, at Ottawa, an American team firing Springfields set marksmanship records for 800 yards, 900 yards, and 1,000 yards that have never been broken. Much is to be said for the men behind these guns, but due credit must be given the rifles that put the bullets where the marksmen aimed.

Such was the history of this splendid arm when the United States neared the brink of the great conflict. But as war became inevitable for us and we began to have a realization of

the scale on which we must prosecute it, our ordnance officers, studying the rifle problem, became persuaded that our Army could not hope to carry this magnificent weapon to Europe as its chief small-arms reliance. A brief examination of the industrial problem presented by the rifle situation in 1917 should make it clear, even to a man unacquainted with machinery and manufacturing, why it was humanly impossible to equip our troops with the rifle in developing which our ordnance experts had spent so many years.

The Model 1903 rifle had been built in two factories and only two—the Springfield Armory, Springfield, Massachusetts, and the Rock Island Arsenal, at Rock Island, Illinois. For several years before 1917, our Government had cut down its expenditures for the manufacture of small arms and ammunition. The Rock Island Arsenal had ceased its production of Springfields altogether, and the output of rifles from the Springfield Armory had been greatly reduced. This meant that the skilled artisans once employed in the manufacture of Springfield rifles had been scattered to the four winds. When, in early 1917, it became necessary to speed up the production of rifles to the limit in these two establishments, those in charge of the undertaking found that they could recover only a few of the old trained employees. Yet, even when we had restaffed these two factories with skilled men, their combined production at top speed could not begin to supply the quantity of rifles which our impending Army would need. It was obviously necessary that we procure rifles from private factories.

Why, then, was not the manufacture of Springfields extended to the private plants? Some ante-bellum effort, indeed, had been made looking to the production of Springfields in commercial plants, but lack of funds had prevented more than the outlining of the scheme.

Any high-powered rifle is an intricate product. The 1917 Enfield is relatively simple in construction; yet the soldier can dismount his Enfield into eighty-six parts, and some of these parts are made up of several component pieces. Many of them

must be made with great precision, gauged with microscopic nicety, and finished with unusual accuracy. To produce Springfields on a grand scale in private plants would imply the use of thousands of gauges, jigs, dies, and other small tools necessary for such a manufacture, as well as that of great quantities of special machines. None of this equipment for Springfield rifle manufacture had been provided; yet all of it had to be supplied to the commercial plants before they could turn out rifles. We should have had to spend preliminary months, or even years, in building up an adequate manufacturing equipment for Springfields, the while our boys in France were using what odds and ends of rifle equipment the Government might be able to purchase for them—except for a condition, present in our small-arms industry in early 1917, that now seems to have been well-nigh providential.

Among other governments, both the British and the Russian, in the emergency of 1914 and 1915, had turned to the United States to supplement their sources of rifle supply while they, particularly the British, were building up their home manufacturing capacity. Five American concerns were engaged in the production of rifles on these large foreign orders when we entered the war. Three of them were the Winchester Repeating Arms Company, of New Haven, Connecticut; the Remington Arms-Union Metallic Cartridge Company, of Ilion, New York; and the Remington Arms Company of Delaware at its enormous war-contract factory at Eddystone, Pennsylvania, later a part of the Midvale Steel & Ordnance Company. These concerns had developed their manufacturing facilities on a huge scale to turn out rifles for the British Government. By the spring of 1917 England had built up her own manufacturing facilities at home, and her last American contracts were nearing completion. Here at hand, then, was a huge capacity which, added to our government arsenals, could turn out every rifle the American Army would require, regardless of how many troops we were to put into the field.

But what of the gun that these plants were making—the British Enfield rifle? As soon as war became a certainty for us,

the Ordnance Department sent its best rifle experts to these private plants to study the British Enfield in detail. They returned to headquarters without enthusiasm for it; in fact, regarding it as a weapon not good enough for an American soldier.

A glance at the history of the British Enfield will make clear some of our objections to it. Until the advent of the 1903 Springfield, the German Mauser had occupied the summit of military-rifle supremacy. From 1903 until the advent of the World War these two rifles, the Mauser and the Springfield, were easily the two leaders. The British Army had been equipped with the Lee-Enfield for some years prior to the outbreak of the World War, but the British ordnance authorities had been making vigorous efforts to improve this weapon. The Enfield was at a disadvantage principally in its ammunition. It fired a .303-caliber cartridge with a rimmed head. From a ballistic standpoint this cartridge was virtually obsolete.

In 1914 a new, improved Enfield, known at the Pattern '14, was brought out in England, and the British Government was on the point of adopting it when the World War broke out. This was to be a gun of .276 caliber and was to shoot rimless, or cannelured, cartridges similar to the standard United States ammunition. The war threw the whole British improved Enfield project on the scrap heap. England was no more equipped to build the improved Enfields than we were to produce Springfields in our private plants. The British arsenals and industrial plants and ammunition factories were equipped to turn out, in the quantities demanded by the war, only the old "short Enfield" and its antiquated .303 rimmed cartridges.

Now, England was obliged to turn to outside sources for an additional rifle supply, and in the United States she found the three firms named above willing to undertake large rifle contracts. Having to build up factory equipment anew in the United States for this work, England found that she might as well have the American plants manufacture the improved Enfield as the older type. To produce the 1914 Enfield without

change in America and the older-type Enfield in England would have complicated the British rifle-ammunition manufacture, since these rifles used cartridges of different sizes and types. Accordingly, the British selected the improved Enfield for the American manufacture, but modified it to receive the .303 rimmed cartridges.

This was the gun, then, that we found being produced at New Haven, Ilion, and Eddystone in the spring of 1917. The rifle had many of the characteristics of the 1903 Springfield, but it was not so good as the Springfield in its proportions, and its sights lacked some of the refinements to which Americans were accustomed. Even so, it was a weapon obviously superior to either the French or the Russian rifle. The ammunition which it fired was out of the question for us. Not only was it inferior, but, since we expected to continue to build the Springfields at the government arsenals, we should, if we adopted the Enfield as it was, be forced to produce two sizes of rifle ammunition, a condition leading to delay and unsatisfactory output. The rifle had been designed originally for rimless ammunition and later modified; therefore it could readily be modified again to shoot our standard .30-caliber Springfield cartridges.

It may be seen that the Ordnance Department had open before it three courses. It could spend the time to equip private plants to manufacture Springfields, in which case the American rifle program would be hopelessly delayed; it could get guns immediately by contracting for the production of British .303 Enfields, in which case the American troops would carry inferior rifles with them to France; or it could take a relatively brief time, accept the criticism bound to come from any delay, however brief such delay might be and however justified by the practical conditions, and modify the Enfield to take our ammunition, in which case the American troops would be adequately equipped with a good weapon. The decision to modify the Enfield was one of the great executive choices of the war. All honor to the men who made it.

The three concerns which had been manufacturing the British weapon conceded that it should be changed to take

the American ammunition. Each company sent to the Springfield Armory on May 10, 1917, a model modified rifle to be tested. The test showed that the weapons were still unsatisfactory, principally because they had not been standardized. Standardization was regarded as an essential for two reasons, one of them a matter of practical tactics in the field and the other a matter of speed in production.

To begin with, the soldier on the battle field is his own rifle repairman. His unit usually has on hand a supply of weapons damaged or out of commission for one reason or another. If, therefore, any part of the soldier's rifle is broken or damaged, he can go to the stock of unused guns on hand and take from another rifle the part which he requires, and it will fit his gun, provided there has been standardization in the rifle manufacture at home. But if the guns have not been standardized and each weapon is a filing and tinkering job in the assembling room of the factory, then the soldier in the field is not likely to be able to find a part that will fit his gun; and his rifle, if damaged, goes out of commission. Or, if he finds a part which fits, but does not fit perfectly, his gun may break as he fires it, and he himself may suffer serious injury. And standardization is equally essential to great speed in production. If one plant producing rifles encounters a shortage in any of the parts, it can send to another plant and secure a supply—an advantage which does not exist unless the weapon has been standardized. The value of standardization in speeding up manufacture is best shown by the actual records of rifle production during the war. The fastest mechanic in any of the three Enfield factories before 1917 had set an assembly record of fifty rifles in one working day for the British gun. After we had standardized the Enfield the high assembly record was 280 rifles a day; and the assemblers in the plants averaged 250 rifles a day when the work was well started.

The Enfields sent to the Springfield Armory test were not standardized at all; they were largely hand fitted. Little or no attempt had been made to obtain interchangeability of parts among the rifles turned out by the three plants. Even the bolt

taken from one company's rifle would not enter the receiver of another company's. The Ordnance Department was confronted with the dilemma of approving and issuing a weapon pronounced unsuitable by its own experts and thus obtaining speedy production, or delaying until interchangeability was established. It chose the latter course.

On July 12 a second set of rifles had been tested. These came more nearly up to our ideas of standardization, but were still not entirely satisfactory. Nevertheless we decided to go ahead with production and improve the standardization as we went along. The Winchester and Ilion plants elected to start work on that understanding, but Eddystone preferred to wait for the final requirements. Ilion afterward decided to postpone production until the final specifications were adopted. It would have been well if the same course had been followed at the Winchester plant, for word came later from Europe not to send over rifles of Winchester manufacture of that period. The final drawings of the standardized and modified Enfield did not come from the plants until August 18. Six days later the thousands of dimensions had been carefully checked and finally approved by the ordnance officers, and after that, production began in earnest.

The wisdom of adopting the Enfield rifle and modifying it to meet our requirements instead of extending the manufacture of Springfields was almost immediately evident, for in August, almost as soon as the final drawings were approved, the first rifles were delivered to the Government. This was possible because the modifications which we adopted did not require any fundamental changing of machinery. The principal equipment of the plants was in place and ready to begin manufacturing Enfields at once; and while the changes in the rifle were under discussion, the manufacturers were producing their gauges and small tools as each modification was decided upon. Though we did not succeed in attaining, and in fact did not attempt to attain, complete standardization and interchangeability of the parts of the Enfields, we did all that was prac-

ticable in this direction. Several tests showed that the average of interchangeability was about 95 per cent of the total parts.

Meanwhile we were building up the working staffs of the Rock Island Arsenal and Springfield Armory and speeding the production of Springfields. Before the war ended, the Rock Island Arsenal, which was making spare parts for Springfields, reached an output equaling 1,000 completed rifles a day; and the Springfield Armory attained a high average of 1,500 assembled rifles a day in addition to spare parts equaling 100 completed rifles daily.

The Eddystone plant finished its British contracts on June 1, Winchester produced its last British rifle on June 28, and Ilion its last on July 21, 1917. Winchester delivered the first modified Enfields to us on August 18, Eddystone on September 10, and Ilion about October 28. Progress in the rate of manufacture was thereafter steady. During the week ending February 2, 1918, the daily production of military rifles in the United States was 9,247, of which 7,805 were modified Enfields produced in the three private plants, and 1,442 were Springfields built in the two arsenals. The total production for that week was 50,873 guns of both types, or nearly enough for three army divisions. In spite of the time that went into the standardization of the Enfield rifle, all troops leaving the United States were armed with American weapons at the ports of embarkation. Ten months after we declared war against Germany we were producing in a week four times as many rifles as Great Britain had turned out in a similar period after ten months of war, and our production was then twice as large in volume as Great Britain had attained in the war up to that time. By the middle of June, 1918, we had passed the million and one-half mark in the production of rifles of all sorts, this figure including over 250,000 rifles which had been built upon original contracts placed by the former Russian Government.

The production of Enfields and Springfields during the war up to November 9, 1918, amounted to 2,506,307 guns. Of these, 312,878 were Springfield rifles produced by the two government arsenals. We had started the war with a reserve

of 600,000 Springfield rifles on hand, and we had in addition, stored in our armories and arsenals, 160,000 Krags. These last had to be cleaned and considerably repaired before they could be used. From the Canadian Government we purchased 20,000 Ross rifles. The deliveries of Russian rifles totaled 280,049. This gave us a total equipment of 3,575,356 rifles. Since approximately one-half the soldiers of an army, as armies are actually organized, carry rifles, the total number of rifles procured by the Ordnance Department was sufficient to arm, both for fighting and for training, an army of 7,000,000 men, if we take no account of reserve and maintenance rifles.

The Enfield became, then, the dominant rifle of our military effort. Its modified firing mechanism could use the superior Springfield cartridges with their great accuracy. The Enfield sights, with the peep sight close to the eye, gave even greater quickness of aim than the Springfield sights afforded. In this respect the weapon was far superior to the Mauser, which was the main dependence of the German Army. To a weapon that made at first but scant appeal to our ordnance officers, we added in a few weeks such improvements and modifications as made the 1917 Enfield a gun that, for the short-range fighting in Europe, compared favorably with the Springfield and was to the Allied cause a distinct contribution which America could claim as substantially her own.

Standardization not only made possible the speed with which our rifles were ultimately produced, but, together with the care of the Government in purchasing raw materials and in drawing contracts, it saved a great deal of money in the cost of these weapons. The modified Enfields cost the Government approximately $26 each, a price considerably under that which the British paid for their American-built Enfields.

Both the Springfield and the 1917 Enfield rifle possessed advantages of accuracy and speed of fire over the German Mauser. It is true that the Mauser fired a heavier bullet than that of our standard ammunition and sent it with somewhat greater velocity; but at the longer fighting ranges the Mauser bullet is not so accurate as the United States bullet. Due to its

peculiar shape, the Mauser bullet is apt to tumble end over end at long ranges—"key-holing," the marksmen call it—particularly when the wind blows across the range. Such tumbling causes a bullet to curve as a baseball thrown by a good pitcher, destroying its accuracy.

Early in our fighting with Germany we captured Mauser rifles and hastened to compare them with the Springfields and modified Enfields. We found in the American rifles a marked superiority in the rapidity of fire, the quickness and ease of sighting, and in the accuracy of shots fired. The accuracy was due not only to our standard Springfield ammunition, but also to the greater mechanical accuracy in the finish of the chamber and bore of the American rifles. The rapidity of fire of the American guns was due to the position and shape of the bolt handle, the movable mechanism with which the soldier ejects a spent shell and throws in a fresh one.

How we developed this bolt handle is an interesting story in itself. In 1903, when we brought out the first modern Springfield rifle, we decided to abandon the old carbine which had been carried by our cavalry regiments and, by making a rifle with a comparatively short barrel, to furnish a gun which could be used by both infantry and cavalry. The original bolt handle of the Springfield, like the one on the present Mauser, had projected horizontally from the side of the chamber. It was found that this protuberance did not fit well in the saddle holster of the cavalryman, but jammed the side of the rifle against the leather of the holster, with frequent injury to the rifle sight. For this reason, primarily, the rifle designers bent the bolt handle down and back. This modification incidentally brought the bolt handle much nearer to the soldier's hand as he fingered the trigger. The Enfield design had carried this development even farther, so that the bolt handle was practically right at the trigger, and the rifleman's hand was ready to pull the trigger the instant after it had thrown in a new cartridge.

Let us see what effect this design of the bolt handle had in the recent war. The Mauser still clung to the old horizontal bolt handle, well away from the trigger grip. Some of our best

riflemen practiced with the captured Mausers and, firing at top speed with them, could not bring the rate of shooting anywhere nearly up to the marks set by the Enfields and Springfields. One enthusiast has even maintained that the speed of the Mauser is not over 50 per cent of that of the 1917 American rifle, but this may be an underestimate. On such a basis, under battle conditions with equal numbers of men on a side, the Americans had in effect two rifles to the Germans' one. To put it another way: By bending back the bolt handle we had placed two men on the firing line where there was only one before; and the added man required no shelter, clothing, rations, water, or pay. Although he sometimes needed repairing, he did not get sick, nor did he ever become an economic burden or draw a pension. His only added cost to the Government was an increased consumption of cartridges.

When American troops were in the heat of the fighting in the summer of 1918, the German Government sent a protest through a neutral agency to our Government, asserting that our men were using shotguns against German troops in the trenches. The allegation was true; but our State Department replied that the use of such weapons was not forbidden by the Geneva Convention, as the Germans had asserted. Manufactured primarily for the purpose of arming guards placed over German prisoners, these shotguns were undoubtedly in some instances carried into the actual fighting. The Ordnance Department procured some 30,000 to 40,000 shotguns of the short-barrel or sawed-off type, ordering them from the regular commercial manufacturers. The shell provided for these guns each contained a charge of nine heavy buckshot, a combination likely to have murderous effect in close fighting.

Such was the rifle record of this Government in the war. The Americans carried into battle the best rifles used in the war, and America's industry produced these weapons in the emergency at a rate which armed our soldiers as rapidly as they could be trained for fighting. Success in such a task looked almost impossible at the start; but that it was attained should forever be a source of gratification to the American people.

Rifle Production to November 9, 1918

Months	*Eddystone*	*Winchester*	*Ilion*	*Springfield Armory*	*Rock Island Arsenal*	*Total*
Before August, 1917 . . .	......	......	......	14,986	1,680	16,666
August 1, 1917, to December 31, 1917	174,160	102,363	26,364	89,479	22,330	414,696
1918						
January	81,846	39,200	32,453	23,890	7,680	185,069
February	98,345	32,660	39,852	6,910	2,460	180,227
March	68,404	42,200	49,538	120	420	160,682
April	87,508	43,600	36,377	2,631	.....	170,116
May	84,929	41,628	54,477	3,420	550	185,004
June	104,110	34,249	52,995	6,140	619	198,113
July	135,080	35,700	60,413	14,841	2,038	248,072
August	106,595	20,030	65,144	27,020	1,597	220,386
September	110,058	31,550	58,027	29,770	3,813	233,218
October	100,214	33,700	53,563	35,920	3,256	226,653
November 1-9, 1918 . . .	30,659	9,100	16,338	10,500	808	67,405
Total	1,181,908	465,980	545,541	265,627	47,251	2,506,307

NOTE.—Eddystone, Winchester, and Ilion plants turned out the United States rifle, caliber .30, Model 1917, popularly known as the Enfield; the Springfield Armory and the Rock Island Arsenal produced the United States rifle, caliber .30, Model 1903, popularly known as the Springfield rifle. The months marked by a drop in the production at Springfield and at Rock Island were months in which the components manufactured, instead of being assembled, were used for spare parts.

CHAPTER XII

PISTOLS AND REVOLVERS

THE American pistol was one of the successes of the war. For several years before the war came the Ordnance Department had been collaborating with private manufacturers to develop the automatic pistol; but none of our officers realized, until the supreme test came, what an effective weapon the Colt .45 would be in the hand-to-hand fighting of the trenches. In our isolation we had suspected, perhaps, that the bayonet and such new weapons as the modern hand grenade had encroached upon the field of the pistol and revolver. We were soon to discover our mistake. In the hands of a determined American soldier the pistol proved to be a weapon of great execution, and it was properly feared by the German troops.

We had long been a nation of pistol shooters, we Americans, but not until the year 1911 did we develop a pistol of the accuracy and rapidity of fire demanded by our ordnance experts. The nations of Europe had neglected this valuable arm almost altogether, regarding it principally as a military ornament which only officers should carry. The result of Europe's neglect was that the small-caliber revolvers of the Germans and even of the French and English were toys in comparison with the big Colts that armed the American soldiers.

America owed the Colt .45 to the experiences of our fighters in the Philippines, and to the inventive genius of John Browning of machine gun fame. In the earlier Philippine campaigns our troops used a .38-caliber pistol. Our soldiers observed that the tough tribesmen, when they were hit with these bullets and even seriously wounded, frequently kept on fighting for some


Photo from Ordnance Department

STRAIGHTENING RIFLE BARRELS


Photo from Des Moines Sawmill Company

WALNUT LOGS TO BE MADE INTO RIFLE STOCKS

Photo from Caron Brothers

PART OF FACTORY MAKING PISTOLS FOR ARMY

Photo from Colt's Patent Firearms Manufacturing Company

MACHINING ROUGH PISTOL CASTINGS

time. What was needed was a hand weapon that would put the adversary out of fighting the instant he was hit, whether fatally or not. We therefore increased the caliber of the automatic pistol to .45 and slowed down the bullet so that it tore flesh instead of making a clean perforation. These improvements gave the missile the impact of a sledge hammer, and a man hit went down every time.

Moreover, in this development great improvement had been made in the accuracy of the weapon, the 1911 Colt being the straightest-shooting pistol ever produced in this country. Even the best of the older automatics and revolvers were accurate only in the hands of expert marksmen. But any average soldier with average training can hit what he shoots at with a Colt. The improvements in the automatic features brought it to the stage where it could be fired by a practiced man twenty-one times in twelve seconds. In this operation the recoil of each discharge ejects the empty shell and loads in a fresh one.

Only a few men of each infantry regiment carried pistols when our troops first went into the trenches. But in almost the first skirmish this weapon proved its superior usefulness in trench fighting. Such incidents as that of the single American soldier who dispersed or killed a whole squad of German bayoneteers which had surrounded him struck the enemy with fear of Yankee prowess with the pistol. The "tenderfoot's gun," as the westerners used to call it, had come to its own.

By midsummer of 1917 the decision had been made to supply to the infantry a much more extensive equipment of automatic pistols than had previously been prescribed by regulations—to build the pistols by hundreds of thousands where we had been turning them out by thousands. In February, with war in sight, realizing the limitations of our capacity for producing pistols at that time,—the Colt automatic being manufactured exclusively by the Colt's Patent Firearms Manufacturing Company, at Hartford, Connecticut, and for a limited period by the Springfield Armory,—we took up with the Colt's Company the proposition to secure drawings and other engineering data which would enable us to extend the production

of this weapon to other plants. This work was in progress when, in April, 1917, it was interrupted by the military necessity for calling upon every energy we had in the production of rifles.

In order to supplement the pistol supply, although the Colt automatic was the only weapon of this sort approved for the Army, the Secretary of War authorized the Chief of Ordnance to secure other small arms, particularly the double-action .45-caliber revolver as manufactured by both the Colt's Company and the Smith & Wesson Company. These revolvers had been designed to use the standard army caliber-.45 pistol cartridges. The revolver was not so effective a weapon as the automatic pistol, and it was adopted in the emergency only to make it possible to provide sufficient of these arms for the troops at the outset.

At the start of hostilities the Colt's Company indicated that it could tool up to produce pistols at the rate of 6,000 a month by December, 1917, and could also furnish 600 revolvers a week beginning in April. As soon as funds were available we let a contract to the Colt's Company for 500,000 pistols and 100,000 revolvers, and to the Smith & Wesson Company one for 100,000 revolvers. Although these contracts were not placed until June 15, both concerns had been working on the production of weapons on these expected contracts for many weeks, in the certainty that funds would eventually be available.

When the order came from France to increase the pistol equipment, in addition to efforts to increase production at the plants of the two existing contractors we made studies of numerous other concerns which might undertake this class of manufacture. A proposal to purchase .38-caliber revolvers as a supplementary supply was abandoned for the reason that any expansion of this manufacture and of that of the necessary ammunition would be at the expense of the ultimate output of .45's and ammunition therefor.

In December, 1917, the Remington Arms-Union Metallic Cartridge Company was instructed to prepare for the manu-

facture of 150,000 automatics, Colt Model 1911, at a rate to reach a maximum production of 3,000 a day. Considerable difficulty was experienced in obtaining the necessary drawings and designs, because the manufacture of these pistols at the Colt's Company plant had been largely in the hands of expert veteran mechanics, who knew tricks of fitting and assembling not apparent in the drawings. The result was that the drawings in existence were not completely representative of the pistols. Finally complete plans were drawn up that covered all details and gave interchangeability between the parts of pistols produced by the Remington Company and those by the Colt's Company, which was the goal sought.

During the summer of 1918, in order to fill the enormously increased pistol requirements of the American Expeditionary Forces, contracts for the Colt automatic were given to the National Cash Register Company, at Dayton, Ohio; the North American Arms Company, Quebec; the Savage Arms Corporation, Utica, New York; Caron Brothers, Montreal; the Burroughs Adding Machine Company, Detroit, Michigan; the Winchester Repeating Arms Company, New Haven, Connecticut; the Lanston Monotype Company, Philadelphia, Pennsylvania; and the Savage Munitions Corporation, San Diego, California. All these concerns, none of which had ever before produced the .45-caliber pistol, were proceeding energetically with their preparations for manufacture when the armistice came to terminate their contracts. No pistols were ever obtained from any except the Colt's Patent Firearms Manufacturing Company and the Remington Arms-Union Metallic Cartridge Company.

Difficulty was experienced in securing machinery to check the walnut grip for the pistols, and to avoid delay in production the Ordnance Department authorized the use of bakelite for pistol grips in all the new plants which were to manufacture the gun. Bakelite is a substitute for hard rubber or amber, invented by the eminent chemist, Dr. L. H. Baekeland.

At the outbreak of the war the Army owned approximately 75,000 .45-caliber automatic pistols. At the signing of the

armistice there had been produced and accepted since April 6, 1917, a total of 643,755 pistols and revolvers. The production of pistols was 375,404 and that of revolvers 268,351. In the four months prior to November 11, 1918, the average daily production of automatic pistols was 1,993 and of revolvers 1,233. This was at the yearly production rate of approximately 600,000 pistols and 370,000 revolvers. These pistols were produced at an approximate cost of $15 each.

Production of Pistols and Revolvers to December 31, 1918

	Pistols			Revolvers			
	Colt	Remington	Total pistols	Colt	Smith & Wesson	Total revolvers	Total pistols and revolvers
April 6 to December 29, 1917	58,500	.....	58,500	20,900	9,513	30,413	88,913
January, 1918	11,000	.....	11,000	8,700	7,500	16,200	27,200
February, 1918	14,500	.....	14,500	8,800	8,550	17,350	31,850
March, 1918	21,300	.....	21,300	11,800	12,400	24,200	45,500
April, 1918	22,400	.....	22,400	10,400	10,650	21,050	43,450
May, 1918	35,000	.....	35,000	11,100	12,150	23,250	58,250
June, 1918	37,800	.....	37,800	11,100	14,250	25,350	63,150
July, 1918	39,800	.....	39,800	11,600	11,555	23,155	62,955
August, 1918	40,400	.....	40,400	11,300	13,358	24,658	65,058
September, 1918	32,100	640	32,740	11,100	12,650	23,750	56,490
October, 1918	42,300	3,881	46,181	13,500	16,675	30,175	76,356
November, 1918	45,800	4,102	49,902	11,900	12,660	24,560	74,462
December, 1918	24,600	4,529	29,129	9,500	11,400	20,900	50,029
Total	425,500	13,152	438,652	151,700	153,311	305,011	743,663

CHAPTER XIII

SMALL-ARMS AMMUNITION

PRIOR to the war with Germany the Ordnance Department, in providing .30-caliber ammunition for our army rifles and machine guns, had thought in terms of millions and had placed its ammunition orders on that scale. But when hostilities were at hand and steel and walnut were being assembled into rifles to arm the indefinitely increasing millions of Yankee soldiers whom we would send and keep on sending to Europe until victory was ours, small-arms ammunition stepped out of the million class and became an industry whose units of production were reckoned by the billion. The war increased the human strength of the American Army approximately thirty times. That ratio of increase was carried over into the production of ammunition for rifles and machine guns. The story of ammunition in the war is the story of a three-billion output forced from a hundred-million capacity. In this effort we find another of those frequent industrial romances which the war produced in America; for, when called upon to do more than an industrial possibility, as we regarded such things in 1917, the contriving executive and organizing ability and the skillful hands of the ammunition industry made good.

Our .30-caliber ammunition capacity in the United States before the war was about 100,000,000 cartridges a year. We actually produced in the war period the huge total of 3,507,023,300 small-arms cartridges. Pushed at feverish haste, such expansion naturally recorded its mistakes and its failures; but none of these was fatal or irremediable. The fact will always remain that a difficult art was enlarged in time to take care of every demand of the American Army for small-arms ammunition, and that no military operation on our part was held

up by lack of this ammunition. Hence is it submitted that the production of small-arms cartridges was one of the genuine achievements of our Ordnance Department.

Let us consider first the production of the .30-caliber service ammunition, which may be regarded as the standard product of the ammunition industry. This was the ammunition used in our two service rifles, the Springfield or United States model of 1903 and the United States model of 1917, a modification of the British rifle, Pattern 1914, and in most of the machine guns which we fired in France (although we used the 8-millimeter cartridge with the Chauchat machine rifle). When the war broke out we had on hand approximately 200,000,000 rounds of .30-caliber cartridges. Most of these had been manufactured by the Government at the Frankford Arsenal, which was, in fact, practically the only plant in the United States equipped to produce this ammunition in appreciable quantities.

Some years before the war, however, the Government had adopted the policy of encouraging the manufacture of army ammunition in private plants. This was done by placing with various concerns small annual orders for this type of ammunition. These orders were usually in the neighborhood of 1,000,000 rounds each. The purpose of such orders, insignificant as they were, was to scatter throughout the principal private ammunition factories the necessary jigs, fixtures, gauges, and other tooling required in the production of cartridges for army rifles and machine guns. These small orders might also be expected to educate the operating forces of the private plants in such manufacture. By this means the Government hoped to have, in an emergency, a nucleus of skill and equipment which could be quickly expanded to meet war requirements.

As a further means of stimulating interest in this peacetime undertaking, the Ordnance Department conducted each year a sort of competition among the private manufacturers of small-arms ammunition. The output of each factory which accepted the government orders was tested for proper functioning and accuracy. Those cartridges which won in this competition were used as the ammunition shot in the national rifle

matches; and the winning concern could use its achievement in its advertising.

But these educational efforts on the part of the Government failed to create a capacity anywhere nearly adequate to the demands of such a war as that into which we were plunged in 1917. We had built up no large reserves of ammunition, and the orders placed with private manufacturers had been so small that they had resulted in virtually no factory preparation at all for great quantity production. For all practical purposes the entire ammunition-manufacturing capacity for .30-caliber cartridges in 1917 was encompassed within the walls of the Frankford Arsenal.

There was, however, in the ammunition industry, as in the manufacture of rifles, one fortunate condition existing when we entered the war. For some time numerous American concerns had been working on the manufacture of cartridges for both the British and the French governments. The cartridges being turned out under these contracts were not suitable for our use, being of different caliber from those taken by American weapons, and this meant that the machinery in existence could not be converted to the production of American ammunition without radical and time-consuming alteration of tools. But cartridges are cartridges, regardless of their size; and the manufacture which was supplying France and England had resulted in educating thousands of mechanics and shop executives in the production of ammunition. Consequently, when we went into the war we had the men and the skill ready at hand; we needed only to produce the tools and the machinery in addition to the raw materials.

Yet this was in itself a problem. How should we meet it? Three courses seemed to be possible for the Government. In the first place, we could build, from the ground up, an immense government arsenal with an annual capacity of 1,000,000,000 rounds, or ten times that of the great Frankford Arsenal. Or we could interest manufacturers in a project of building a private cartridge factory capable of producing 1,000,000,000 rounds a year. Both of these methods were predicated on the

assumption that the existing cartridge factories had their hands full with orders. The third plan was to place our cartridge demands with the existing ammunition plants and let them increase their facilities to take care of our orders.

As soon as the early orders had been given and all available capacity had been set going, this problem engaged the study and attention of the Ordnance Department. In the early fall of 1917 a meeting of the manufacturers of small-arms ammunition was held in Washington to discuss the matter. Principally on account of the difficulties in providing a trained working force for a new government arsenal or private plant, the opinion was unanimous that the existing concerns should expand in facilities and trained *personnel* to handle the cartridge project. Out of this meeting grew the American Society of Manufacturers of Small Arms and Ammunition. Thereafter until the close of the war this society or its committees met about once every two weeks to discuss problems arising in the work. The officers of the Ordnance Department in charge of the ammunition project attended all these meetings. The result of such coöperation was gratifyingly shown, not only in the standardization of manufacturing processes in the various plants, but also in the output of cartridges.

The success of this effort is best shown in the production figures of the period from April, 1917, to November 30, 1918. In that time the United States Cartridge Company turned out 684,334,300 rounds of our caliber-.30 service ammunition; the Winchester Repeating Arms Company, 468,967,500 rounds; the Remington Arms-Union Metallic Cartridge Company, 1,218,979,300; the Peters Cartridge Company, 84,169,800; the Western Cartridge Company, 48,018,800; the Dominion Arsenal, 502,000; the Frankford Arsenal, 76,739,300; and the National Brass & Copper Tube Company, 22,700,400.

This production record was to some extent facilitated by a leniency on the part of the Ordnance Department which it had not displayed before the war. When we could take plenty of time in ammunition manufacture our specifications for car-

tridges were extremely rigid. It soon became evident that if we adhered to our earlier specifications we should limit the output of cartridges. It was found, in a joint meeting of ordnance officers and ammunition manufacturers, that certain increased tolerances could be permitted in our specifications without affecting the serviceability of the ammunition. Consequently, new specifications for our war ammunition were drawn, which enabled the plants to get into quantity production much more quickly than would have been possible if we had not relaxed our prewar attitude.

The ordinary service cartridge consists of a brass cartridge case, a primer, a propelling charge of smokeless powder, and a bullet made with a jacket or envelope of cupronickel enclosing a lead slug or core. Cupronickel is a hard alloy of copper and nickel. Steel would be the ideal covering for a bullet, because of its cheapness and availability, but steel has not been used, because it is likely to rust and also to cut the delicate rifling of the gun barrel. Cupronickel is a compromise, being strong enough to hold the interior lead from deforming, but not so hard as to wear down excessively the rifling in the gun barrel. Even when we entered the war, the long continued fighting in Europe had created a shortage in cupronickel, and by the time of the armistice it was clear that this shortage would soon become so acute as to compel our finding a substitute for cupronickel. This shortage had already occurred in Germany, where the enemy ordnance engineers had produced a bullet encased in steel which in turn was clothed with a slight covering of copper. The soft copper coating kept the steel from injuring the gun barrel. We ourselves were experimenting with copper-coated steel bullets when peace came, and should have been prepared to furnish a substitute had cupronickel failed us.

Some of the earliest ammunition sent to our forces in France developed a tendency to hang fire and to misfire; and a liberal quantity of it, amounting to six months' production of the Frankford Arsenal, was condemned and withdrawn from use. This matter was fully aired in the newspapers at the time. It transpired that the faulty ammunition had been produced

entirely in the Frankford Arsenal and that the cause of the trouble was the primer in the cartridge. The primer performs the same function that the flint did on the old-fashioned squirrel guns: it touches off the explosive propellant charge. But the flint sent only a spark into the powder, whereas the modern primer produces a long, hot flame. The primers in the ammunition manufactured at the Frankford Arsenal had given ordinarily satisfactory results in twelve years of peace-time use. The flame charge in this primer contained sulphur, potassium chlorate, and antimony sulphide. Produced under normal conditions, with plenty of time for drying, this primer was satisfactory. But sulphur, when oxidized, changes to an acid extremely corrosive to metal parts, and oxidized primers are liable to imperfect functioning. Heat and moisture accelerate the change of sulphur to acid; and if there happens to be bromate in the potassium chlorate of the priming charge, the change is even more rapid. An investigation of the Frankford Arsenal showed that these very elements were present. Because of the haste of production of cartridges, too much moisture had been allowed to get into the arsenal dry houses. The potassium chlorate was also found to contain appreciable quantities of bromate. The condition was remedied by adopting another primer composition. And then, to play doubly safe, the government specifications were amended to prevent the use of potassium chlorate containing more than .01 per cent of bromate. This condemned ammunition was but a trifling fraction of the total output, or even of the production then going on. The primers used by the various private manufacturers of ammunition functioned satisfactorily. Although we were not rigid in our specifications for the bulk of the service ammunition, in one point we were most meticulous: in respect to the ammunition used by the machine guns mounted on our airplanes. For these weapons we created an A1 class of service .30-caliber cartridges; for it was highly important that there be no malfunctioning of ammunition in the air. Every cartridge of this class had to be specially gauged throughout its manufacture. This care resulted in a slower production of airplane cartridges

than of those for use on the ground, but we always had enough for our needs.

Until we went to war with Germany our Army had known only the cartridge which fired the hard-jacketed lead bullet. But we entered a conflict in which several novel sorts of small-arms projectiles were in familiar use; and it became necessary for us to take up the manufacture of these strange missiles at once. They included such special types as tracer bullets to indicate the path of fire in the air, incendiary bullets for setting on fire observation balloons, hostile planes, and dirigible airships, and, finally, armor-piercing bullets for use against the armor plate with which airplanes and tanks were equipped. We had developed none of these in this country before the war, except that in the Frankford Arsenal our designers had done some little experimental work with armor-piercing ammunition, carrying it, in fact, to the point of an efficient design.

One of the first acts of the Ordnance Department was to send an officer to visit the ammunition factories of France and England to study the methods of manufacturing these special types of bullets. These friendly nations willingly gave us full information at first hand with respect to this complicated manufacture, which we were thus enabled to begin in September, 1917. Special machinery was required for loading the tracer bullet and also for producing the incendiary projectile. We adopted British practice for both of these. We ourselves were well equipped to begin the production of the armor-piercing bullet, for which we had previously solved the problems of design; yet the production of metals to be used in this missile required some further experimental work. By February, 1918, however, our production of armor-piercing bullets was well under way, and by the time the war came to an end we had produced nearly 5,000,000 of them.

The tracer bullet which we manufactured contained a mixture of barium peroxide and magnesium and in flight burned with the intensity of a calcium light. These bullets were principally used by machine gunners of aircraft, since in the air it is impossible to tell where machine gun projectiles are going

unless there is some device which enables the gunner to see their trajectory. The device used was to insert tracer bullets at intervals in the belts of cartridges fed into the machine gun. The common conception of a tracer bullet is one that leaves a trail of smoke in its flight; whereas our tracer and the British tracer were practically smokeless, the gunner observing the direction of aim by following with his eye the bright lights of the tracer bullets. These lights were plainly visible in the brightest sunlight. Although the slight quantity of the flaming mixture burned but a few seconds, it was sufficient to trace the flight for 500 yards or more from the muzzle of the machine gun. The tracer bullet consisted of a cupronickel shell, the nose of which contained a leaden core to balance the bullet properly. The rear chamber of the bullet held a cup containing the mixture of barium peroxide and magnesium. The rear end of the bullet was left slightly open, and through this opening the mixture was ignited by the hot flame of the propelling powder discharge.

An entirely different principle was used in the construction of the incendiary bullet. This bullet was also encased in cupronickel; but the incendiary chemical, which was phosphorus, was contained in a chamber in the nose of the bullet. A serrated plug held the phosphorus in its chamber, and behind this plug was a solid plug of lead coming flush with the base of the bullet and soldered thereto. On one side of the missile was a hole drilled through the cupronickel into one of the grooves of the serrated plug. This hole was stopped by a special kind of solder. The heat of friction developed in the infinitesimal space of time while the projectile was passing through the gun barrel served the double purpose of melting out the solder from the hole and igniting the phosphorus within the chamber. Thereafter the centrifugal force of the revolving bullet whirled the burning phosphorus out through the unplugged hole. In the air the fire of the phosphorus could not be discerned, but the burning chemical threw off considerable smoke, so that the eye of the gunner could follow the blue spiral to its mark. Our

incendiary bullet had an effective range of 350 yards, after which distance the phosphorus was burned out.

Equally interesting was the construction of the armor-piercing bullet. Heavy and solid as the jacketed lead bullet used in our service guns seems to be, when fired against even light armor plate it leaves only a small mark upon its objective. As soon as the cupronickel jacket strikes the armor plate it splits and the lead core flattens out and flies into fragments. The armor plate may not even be dented by this impact. But change the core of this missile from lead to hardened steel, and an entirely different result is produced. Our armor-piercing bullet was made with a cupronickel jacket for the sake of the gun barrel. The inner side of this jacket was lined with a thin coat of lead, which was made thicker in the nose of the bullet. A core of specially heat-treated steel completed the construction of the projectile. When this missile was fired against armor plate the jacket split and the lead lining virtually disappeared from the impact, but the pointed steel core kept on and bored a hole through the plate as it might through soft wood.

The production figures show the degree of success which we attained in the manufacture of these special types of ammunition. Up to November 30, 1918, the E. I. DuPont de Nemours Company had produced 6,057,000 tracer cartridges of .30 caliber and 1,560,000 incendiary cartridges of the same size. The Frankford Arsenal turned out 22,245,000 tracer cartridges of this size, 14,148 incendiary cartridges, and 4,746,900 armor-piercing cartridges. We placed an additional order for armor-piercing projectiles with the Dominion Arsenal, which delivered to us 1,980,000 such cartridges.

We also set out to develop new manufacturing facilities for the production of this special aircraft ammunition. Excellent tracer bullets were produced by the National Fireworks Company, of West Hanover, Massachusetts, and that company was getting into a satisfactory production stride when the armistice was signed. The Hero Manufacturing Company, of Philadelphia, was also turning out an approved incendiary

bullet when peace came. These various special bullets were loaded in cartridges at the Frankford Arsenal.

When the fighting ceased we were working on the development of armor-piercing bullets that would also be incendiary and of armor-piercing bullets that would also contain a tracing mixture. It was thought that bullets of these types would be particularly valuable for aircraft use. Although we had done considerable experimenting toward both these ends, no satisfactory types had yet been developed.

There was another class of small arms for which we also had to produce ammunition on a war scale. Our automatic pistols and revolvers demanded .45-caliber ball cartridges. In normal times the Frankford Arsenal had been almost our sole producer of these cartridges, and it had attained an annual output of approximately 10,000,000 rounds of them. This quantity was nowhere nearly adequate for our war needs, especially after the decision to equip our troops much more numerously with pistols and revolvers than we had formerly done. Consequently it was necessary for us to develop additional manufacturing facilities for .45-caliber ammunition. We did this by placing orders with some of the same manufacturers who were developing the .30-caliber production. Because it was necessary for us to give preference always to rifle and machine gun ammunition, the manufacture of pistol cartridges was not carried through so rapidly as some other phases of the ammunition program; but a satisfactory output was reached in time to meet the immediate demands of our forces in the field, and this production was expanding and keeping ahead of the increased needs of this sort of cartridge. The total war production of .45-caliber ammunition by the various factories was as follows:

United States Cartridge Company	75,500,000
Winchester Repeating Arms Company	46,446,800
Remington Arms-Union Metallic Cartridge Company	144,825,700
Peters Cartridge Company	55,521,000
Frankford Arsenal	12,349,200

Early in 1918 our air service field forces saw the need of a machine gun of larger caliber than the quick-firing weapons in general use. The flying services of the principal Allies had developed an 11-millimeter machine gun for use in attacking the captive balloons of the enemy. This gun fired a projectile only slightly less than one-half inch in diameter. To meet this new demand our Ordnance Department found at the Colt's factory about 1,000 Vickers machine guns which were being built on order for the former Russian Government. The Department took over these guns and modified them to take 11-millimeter ammunition; and that step made it necessary for us to produce machine gun cartridges for these new weapons. We at once developed a modified French 11-millimeter tracer incendiary cartridge, which in later use proved highly satisfactory. In an experimental order the Frankford Arsenal turned out about 100,000 of these cartridges, and at the time the armistice was signed the Western Cartridge Company was prepared to produce this class of ammunition on a large scale.

Even before April, 1917, certain American concerns had been producing 8-millimeter ammunition for the French Government for use in its machine guns. When we entered the war our Ordnance Department found it necessary to continue the manufacture of these cartridges for the machine guns obtained by the A. E. F. from the French. Up to November 30, 1918, a total of 269,631,800 rounds had been produced under our supervision. These cartridges were manufactured by the Western Cartridge Company and by the Remington Arms Company at its Swanton plant.

How well and amply we were producing ammunition for our machine guns and rifles is indicated by the fact that our average monthly production, based on our showing in July, August, and September, 1918, was 277,894,000 rounds, as against a monthly average for Great Britain of 259,769,000 rounds and for France of 139,845,000. Our total production of machine gun and rifle ammunition during the nineteen months of warfare was 2,879,148,000 rounds. In the same

period England produced 3,486,127,000 rounds and France 2,983,675,000; but it must be remembered that they had been keyed up to that voluminous production by three years of fighting and that our monthly production rate indicated that we should soon far surpass them.

The following table shows how our production of ammunition for all small arms, including machine guns, rifles, pistols, and revolvers, grew month by month during the war:

	Rounds		*Rounds*
November 30, 1917	156,102,792	July 31, 1918	2,306,999,284
December 31, 1917	351,117,928	August 31, 1918	2,623,847,546
January 31, 1918	573,981,712	September 30, 1918	2,942,875,786
February 28, 1918	760,485,688	October 31, 1918	3,236,396,100
March 31, 1918	1,021,610,956	November 30, 1918	3,507,023,300
April 30, 1918	1,318,298,492	December 31, 1918	3,741,652,200
May 31, 1918	1,616,142,052	January 31, 1919	3,940,682,744
June 30, 1918	1,958,686,784		

CHAPTER XIV

TRENCH-WARFARE MATERIAL

LIKE many of the other war implements produced by the Ordnance Department for use in France, the weapons employed in fighting from the trenches were entirely novel to American industry; and in the production of them we find the same story of difficulties in the adoption of foreign designs, of the development of our own designs, of delays encountered and mistakes made in equipping a new industry from the ground up, and, finally, of the triumphant arrival at quantity production in a marvelously brief time, considering the obstacles which had to be overcome.

When the movements of armies in the World War ceased and they were held in deadlock in the trenches, the fighters at once began devising weapons with which they could kill each other from below ground. For this purpose they borrowed from human experience running back to time immemorial. They took a leaf from the book of the Roman fire-ball throwers and developed the hand grenade beyond the point to which it had been brought in the European warfare of the last century. They called upon an industry which had once existed solely for the amusement of the people, the fireworks industry, to contribute its golden rain and rainbow-hued stars as signals with which to talk by night. Other geniuses of the trenches took empty cannon cartridges and, setting them up as ground mortars, succeeded in throwing bombs from them across No Man's Land into the enemy ranks. They even for a time resurrected the catapult of Trojan days, although this device attained no great success. But from all such activities new weapons of warfare sprang, crude at first, but later refined as only modern science and manufacture could make them.

Photo from Ordnance Department

TYPES OF SMALL-ARMS AMMUNITION

Left to Right: (1) Ordinary Jacketed Bullet, (2) Incendiary, (3) Tracer, (4) Armor Piercing

Photo by Signal Corps

WOMAN WORKER IN SMALL-ARMS AMMUNITION FACTORY

Photo from Ordnance Department

HAND GRENADES

Left to Right: (1) Defensive, (2) Offensive, (3) Gas, (4) Phosphorus

Photo from Stenotype Company

WATERPROOFING RIFLE GRENADES

America entered the war when this development of ordnance novelties had reached an advanced state. It became necessary for us, then, to make a rapid study of what had been done and then go ahead with our own production, either from foreign designs or with inventions of our own.

To this end, in April, 1917, a few days after we declared war against Germany, the Trench Warfare Section was organized within the Ordnance Department and given charge of the production of these novelties. The section did not entirely confine itself to trench-warfare materials: one of its chief production activities was concerned with the manufacture of the various sorts of bombs to be dropped from airplanes. Also, at the beginning of its existence it had charge of the production of implements for fighting with poison gas and flame. Although in large part this phase of its work was taken away from it in the summer of 1917 and later placed under the jurisdiction of the newly organized Chemical Warfare Service, the Trench Warfare Section continued to conduct certain branches of gas-warfare manufacture, in particular the production of the famous Livens projectors of gas and also the manufacture of the portable toxic-gas sets for producing gas clouds from cylinders. Altogether, the Trench Warfare Section was charged with the responsibility of producing some forty-seven devices, every one of them new to American manufacture and some extremely difficult to make. The backbone of the program consisted of the production of grenades, of both the hand-thrown and the rifle-fired varieties, trench mortars, trench-mortar ammunition, pyrotechnics of various sorts, and bombs for the airplanes, with their sighting and release mechanisms.

In the production of these new devices there arose, under the tutelage of the Trench Warfare Section, a new form of coöperation between Government and private manufacturers. The manufacturers engaged in the production of various classes of these munitions novelties joined in formal associations. There was a Hand Grenade Manufacturers' Association, under the capable leadership of William Sparks, president of the Sparks-Withington Company, of Jackson, Michigan; the Drop

Bomb Manufacturers' Association, headed by J. L. Sinyard, president of A. O. Smith Corporation, Milwaukee; the Six-inch Trench-mortar Shell Manufacturers' Association, R. W. Millard, president of Foster-Merriam Company, Meriden, Connecticut; the Rifle Grenade Manufacturers' Association, under the leadership of F. S. Briggs, president of the Briggs & Stratton Company, Milwaukee, Wisconsin; and the Livens Projector Manufacturers' Association. A similar association of manufacturers engaged in army contracts existed in the production of small-arms ammunition; but in no other branch of the Ordnance Department was the development of such cooperation carried on to the extent of that fathered by the Trench Warfare Section.

The existence of these associations was of inestimable benefit in securing the rapid development, standardization for quantity manufacture, and production of these strange devices. Each association had its president, its other officers, and its regular meetings. These meetings were attended by the interested officers of the Trench Warfare Section. In the meetings the experiments of the manufacturers and the short-cut methods developed in their shops were freely discussed; and, if modifications of design were suggested, such questions were debated out in these meetings of practical technicians, and all the contractors simultaneously received the benefits.

The Trench Warfare Section produced its results under the handicap of being low in the priority ratings, many other items of ordnance being considered in Washington of more importance than the trench-fighting materials and therefore entitled to first call upon raw materials and transportation. In the priority lists the leader of forty-seven trench-warfare articles, the 240-millimeter mortars, stood twenty-second, and the others trailed after.

GRENADES

The first of the trench-warfare weapons with which the rookie soldier became acquainted was the hand grenade; for this, at least in its practice or dummy form, was supplied to the

training camps in this country. To all intents and purposes the hand grenade was a product of the war against Germany, although grenades had been more or less used since explosives existed. All earlier grenades had been crude devices with only limited employment in warfare; but in the three years preceding America's participation in the war the grenade had become a carefully built weapon.

The extent of our production of hand grenades may be seen in the fact that, when the effort was at its height, 10,000 workers were engaged exclusively in manufacture of them. The firing mechanism of the explosive grenades which we built was known as the Bouchon assembly. In the production of this item, nineteen of every twenty workers were women. In fact, no other item in the entire ordnance field was produced so exclusively by women. Incidentally, at no time during the war was there a strike in any grenade factory.

For a long time only one type of hand grenade was used in the trenches of France. This was the so-called defensive grenade, built of stout metal which would fly into fragments when the interior charge exploded. As might be expected, such a weapon was used only by men actually within the trenches, the walls of which protected the throwers from the flying fragments. But as the war continued, six other distinct kinds of grenades were developed, America herself contributing one of the most important of them; and during our war activities we were engaged in manufacturing all seven.

The defensive or fragmentation-type grenade was the commonest, most numerous, and perhaps the most useful. Another important one, however, was that known as the offensive grenade, and it was America's own contribution to trench warfare. The body of the offensive grenade was made of paper, and its deadly effect was produced by the flame and concussion of the explosion itself. It was quite sure to kill any man within three yards of it when it went off; yet it was safe to use in the open offensive movements, for there were no pieces of metal to fly back and hit the thrower.

A third development was known as the gas grenade. It was

built of sheet metal, and its toxic contents were effective in making enemy trenches and dugouts uninhabitable. A fourth, a grenade of similar construction, was filled with phosphorus instead of gas, and was known as the phosphorus grenade. This grenade scattered burning phosphorus over an area three to five yards in diameter and released a dense cloud of white smoke. In open attacks upon machine gun nests, phosphorus grenades were thrown in barrages to build smoke screens for the attacking forces.

A fifth class was a combination hand and rifle grenade, a British device adopted in our program. The sixth class of grenades was known as the incendiary type. These were paper bombs filled with burning material and designed for use against structures intended to be destroyed by fire. Finally, in the seventh class, were the thermit grenades, built of terneplate and filled with a compound containing thermit, which develops an intense heat while melting. Thermit grenades were used principally to destroy captured guns. One of them touched off in the breech of a cannon would fuse the breechblock mechanism and destroy the usefulness of the weapon.

All these except the incendiary grenade used the same firing mechanism, and the incendiary grenade firing mechanism was the standard one modified in a single particular.

The earliest American requirement in this production was for defensive grenades of the fragmentation type. Our first estimate was that we should need 21,000,000 of these for actual warfare and 2,000,000 of the unloaded type for practice and training work. But, as the war continued and the American plans developed in scale, we saw that we should require a much greater quantity; and orders were finally placed for a total of 68,000,000 live grenades and over 3,000,000 of the practice variety.

By August 20, 1917, the Trench Warfare Section had developed the design and the drawings for the defensive grenade. The first contract—for 5,000 grenades—was let to the Caskey-Dupree Company of Marietta, Ohio. This concern was fairly entitled to such preference, because the experimentation lead-

ing up to the design for this bomb had been conducted almost entirely at its plant in Marietta.

Next came an interesting industrial development by a well-known American concern which had previously devoted its exclusive energy to the production of high-grade silverware, but which now, as a patriotic duty, undertook to build the deadly defensive grenades. This was the Gorham Manufacturing Company of Providence, Rhode Island. This firm contracted to furnish complete, loaded grenades, ready for shipment overseas, and was the only one to build and operate a manufacturing and loading plant. Elsewhere, contracts were let for parts only, these parts to converge at the assembling plants later; and such orders were rapidly placed until, by the middle of December, 1917, various industrial concerns were tooling up for a total production of 21,000,000 of these missiles. The remodeling of factories, the building of machines, and the manufacture of tools for this undertaking, pushed forward with determined speed, were completed in from 90 to 120 days, and by April almost all the companies had reached the stage of quantity production.

The grenade which these contractors undertook to produce was an American product in its design, although modeled after grenades already in use at the front. Its chief difference was in the firing mechanism, in which certain improvements, or what were then thought to be improvements, had been installed to make it safer in the hands of the soldier than the grenades then in use at the front. This firing mechanism, with its pivoted lever, was, in fact, a radical departure from European practice. The body of this grenade was of malleable iron, and the grenade exploded with a force greater than that of any in use in France.

And then, on May 9, 1918, came a cablegram from the American Expeditionary Forces that brought the entire effort to an abrupt halt. The officers of the American Expeditionary Forces in no uncertain terms condemned the American defensive grenade. The trouble was that, in our anxiety to protect the American soldier, we had designed a grenade that was too

safe. The firing mechanism was too complicated. In the operation required to touch off the fuse, five movements were necessary on the part of the soldier, and in planning these the psychology of a man in battle had not been taken sufficiently into consideration. The well-known story of the negro soldier who, in practice, threw his grenade too soon because he could feel it "swelling" in his hand, applies to most soldiers in battle. In using the new grenade the American soldier would not go through the operations required to fire its fuse. Instances came to light, too, showing that in the excitement of battle the American soldier forgot to release the safety device, thus giving the German an opportunity to hurl back the unexploded grenade.

As the result of this discovery, all production was stopped in the United States and the ordnance engineers began redesigning the weapon. The incident meant that 15,000,000 rough castings of grenade bodies, 3,500,000 assembled but empty grenades, and 1,000,000 loaded grenades had to be salvaged, and that on July 1, 1918, the production of live fragmentation grenades in this country was represented by the figure zero. Some of the machinery used in the production of the faulty grenades was useless and had to be replaced by new; and the trained forces which had reached quantity production in April had to be disbanded or transferred to other work while the design was being changed.

By August 1 the new design had been developed on paper, and much of the new machinery had been produced and installed in the plants, which were ready to go ahead immediately with the production. It is a tribute to the patriotism of the manufacturers who lost time and money by this change that little complaint was heard from them by the Government.

In the production of hand grenades the most difficult element of manufacture, the one item that might have held up the delivery of completed mechanisms, was the Bouchon assembly. There was an abundant foundry capacity in the United States for the production of gray-iron castings for grenade bodies, and this part of the program gave no anxiety.

The Bouchon assembly threatened to be the choke point. In order to assure the success of defensive grenade production, the Precision Castings Company of Syracuse, New York, and the Doehler Die Castings Company of Toledo, Ohio, and Brooklyn, New York, worked their plants twenty-four hours a day until they had built up a reserve of Bouchons and screw plugs and removed all anxiety on that score. The total production of Bouchons eventually reached the figure 64,600,000.

The first thought of the Ordnance Department was to produce grenades by the assembling and quantitative method; that is, by the production of parts in various plants and the assembling of those parts in other plants. But, because of delay in railway shipments and difficulties due to priorities, it was discovered that this method of manufacture, however adaptable it might be to other items in the ordnance program, was not a good thing in grenade production; and when the war ended the tendency was all in the direction of having the assembly contractors produce their own parts, either by purchase from subcontractors or by manufacture in their own plants.

The orders for the redesigned grenades called for the construction of 44,000,000 of them. So rapidly, this time, were the manufacturers able to reach quantity production that a daily rate of 250,000 to 300,000 was attained by November 11, 1918, and by December 6, less than a month after the fighting stopped, the factories had turned out 21,054,339 defensive grenades. It should be remembered that the great effort in ordnance production in this country was directed toward the American offensive expected to occur on a tremendous scale in the spring of 1919. Had the war continued, the fragmentation grenade program, in spite of the delays encountered in its development, would have produced a sufficient quantity of the weapons.

Special consideration is due the following-named firms for their efforts in developing the production of defensive grenades:

Caskey-Dupree Company, Marietta, Ohio.

Spacke Machine & Tool Company, Indianapolis, Indiana.
Stewart-Warner Speedometer Corporation, Chicago, Illinois.
Miami Cycle & Manufacturing Company, Middletown, Ohio.
American Radiator Company, Buffalo, New York.
International Harvester Company, Chicago, Illinois.
Doehler Die Castings Company, Brooklyn, New York.
Precision Castings Company, Syracuse, New York.

The American offensive grenade was largely the production of the Single Service Package Corporation of New York, both in design and in manufacture. The body of this grenade was built of laminated paper, spirally wound and waterproofed by being dipped in paraffine. The top of the body was a die casting, into which the firing mechanism was screwed. Practically no changes were made in the design of this weapon from the time it was first produced, and the production record is an excellent one.

Our earliest thought was that we should need some 7,000,000 of these grenades, and orders for that quantity of bodies were placed in January and March, 1918, with the Single Service Package Corporation. Then it became necessary to discover factories which could produce the metal caps. The orders for these were first placed with the Acme Die Castings Company and the National Lead Casting Company, for 3,375,000 castings from each concern. But these companies failed to make satisfactory deliveries, and in May, 1918, a contract for 5,000,000 caps was let to the Doehler Die Castings Company, which reached quantity production in August. After that, the Single Service Package Corporation, the chief contractor, forged ahead in its work, and on November 11 was producing the bodies for offensive grenades at the rate of 55,000 to 60,000 daily. By December 6, 1918, the Government had accepted 6,179,321 completed bodies. The signing of the armistice brought to an end a project to build 17,599,000 additional grenades of this type.

The production of gas grenades offered some peculiar difficulties. We set out at first to produce 3,684,530 of them. By January, 1918, the engineers of the Ordnance Department had completed the plans and specifications for the American gas

grenade, and on February 12 an order for 1,000,000 of them was placed with the Maxim Silencer Company of Hartford, Connecticut. The gas grenades were to be delivered at the filling plants complete except for the detonator thimbles, which seal both gas and phosphorus grenades and act as sockets for the firing mechanism. It was seen that the construction of these thimbles might be a choke point in the construction of grenades of both types, and orders were early placed for them—1,500,000 to be delivered by the Maxim Silencer Company and an equal quantity by the Bassic Company of Bridgeport, Connecticut. On December 6, 1918, these concerns had produced 1,982,731 detonator thimbles.

The body of the gas grenade is built of two sheet-metal cups welded together to be gas-tight. Since, when we started out on this production, we did not know what kind of gas would be used or at what pressure it would be held within the grenade, we specified that grenade bodies should be made to hold an air pressure of 200 pounds. The welding of the cups frequently failed to hold that pressure, so that the rejections of gas grenade bodies under this test ran as high as 50 per cent. But in June, 1918, the gas for the grenades had been developed, and we were thereupon able to reduce the pressure of the standard test to 50 pounds. Under such a test the bodies readily passed inspection.

In September, 1918, we let additional contracts for gas grenades—500,000 to the Evinrude Motor Company of Milwaukee; 500,000 to the John W. Brown Manufacturing Company of Columbus, Ohio; and 400,000 to the Zenite Metal Company of Indianapolis. On November 11 gas grenade bodies were being produced at the rate of 22,000 a day, and the total production up to December 6 was 936,394.

The phosphorus grenade was similar to the gas grenade in construction. The plans and specifications for this weapon were ready in January, 1918. In February the following contracts were let: Metropolitan Engineering Company, Brooklyn, New York, 750,000; Evinrude Motor Company, Milwaukee, 750,000; Zenite Metal Company, Indianapolis, 500,000. On De-

cember 6, 1918, these concerns had delivered a total of 521,948 phosphorus grenade bodies.

The difficulties which had been experienced in the production of gas grenades were repeated in this project. The Evinrude Company was especially quick in getting over the obstacles to quantity production. The Metropolitan Engineering Company, already engaged with large orders for adapters and boosters in the heavy-gun ammunition manufacture for the Ordnance Department, found that the order for phosphorus grenades conflicted to a considerable extent with its previous war work. The matter was threshed out in the Ordnance Department, which gave the priority in this plant to the adapters and boosters, with the result that the firm was able to make only a small contribution to the total production of phosphorus grenade bodies.

The development of thermit grenades was still in the experimental stage when the armistice was signed. There was no actual production in this country of grenades of this sort. In October, however, the design of the grenade had reached such a stage that we felt justified in letting a contract for 655,450 die-casting parts to the Doehler Die Castings Company, at its Toledo plant, and for an equal number of bodies, with firing-mechanism assemblies, to the Stewart-Warner Speedometer Corporation at Chicago.

Not only did the incendiary grenade not get out of the development stage, but a perfected model was even regarded as of doubtful value by the officers of the American Expeditionary Forces. Nevertheless, the Chemical Warfare Service was of the opinion that such a grenade should be worked out, and an order for 81,000 had been given to the Celluloid Company of Newark, New Jersey. Experimental work was progressing satisfactorily when the armistice was signed.

When the war ended, we were adapting to American manufacture a combination hand and rifle phosphorus grenade, borrowed from the English. The body of this grenade was built of terneplate, and the grenade had a removable stem, so that it could be thrown by hand or fired from the end of a service

rifle. The American Can Company built 1,000 of these to try out the design and strengthen the weak features.

Production of Grenades

Article	*Completed to Nov. 8, 1918*	*Completed to Feb. 1, 1919*	*Sent overseas*
Dummy hand grenade . .	415,870	415,870	......
Practice hand grenade . .	3,605,864	3,605,864	......
Defensive hand grenade .	17,477,245	25,312,794	516,533
Offensive hand grenade . .	5,359,321	7,000,000	173,136
Gas hand grenade . . .	635,551	1,501,176	249,239
Phosphorus hand grenade .	505,192	521,948	150,600
Thermit hand grenade . .	......	......	......

NOTE.—All the above figures, with the exception of those for grenades sent overseas, represent unloaded grenades.

RIFLE GRENADES

IN the construction of our rifle grenades there occurred another unfortunate experience due to a faulty design. The rifle grenade fits into a holder at the muzzle of an ordinary service rifle. When the rifle is fired the bullet passes through a hole in the middle of the grenade, and the gases of the discharge, following the bullet, throw the grenade approximately 200 yards. Any man within 75 yards of an exploding rifle grenade is likely to be wounded or killed. The rifle grenade is used as both a defensive and offensive weapon, the firer being well out of range of the exploding missile.

In developing a rifle grenade for American manufacture our engineers adopted the French Viven-Bessière type. The French service ammunition is larger than ours, and it was therefore necessary to design our grenade with a smaller hole. But in the anxiety to produce this weapon in the shortest possible time, the models were not sufficiently tested, and no consideration was taken of the difference in design between a French bullet and an American bullet. The result was that the French grenade did not function well with our ammunition, its fail-

ure being due to the splitting of the Springfield bullet as it passed through the grenade. In May, 1918, several months after the manufacture of this grenade had been in progress, the entire undertaking was canceled pending the development of new designs; and 3,500,000 completed grenades had to be salvaged.

The original contract for rifle grenades had been let to the Westinghouse Electric & Manufacturing Company of Pittsburg. This called for the production of all parts by the Westinghouse Company and the assembling of them in the Westinghouse plant to the number of 5,000,000 grenades. But there was such a diversity of material employed in the manufacture of rifle grenades that succeeding contracts for parts and for assembling were let separately. After the rifle grenade had been redesigned, new contracts were let for a total of 30,115,409 of them. In August, a few weeks later, the daily production of these grenades in the various plants had reached a total of 130,000, and by the end of October the daily production was 250,000. The goal toward which this production was aiming was the expected spring offensive of the American Expeditionary Forces in 1919. We should have met this event adequately, because, though only 685,200 American rifle grenades had actually been shipped overseas when the fighting ceased, we had 20,000,000 of them ready for loading at that time, and the production was already heavy and constantly increasing.

Special consideration is due the following-named firms for their efforts in developing the production of rifle grenades:

Westinghouse Electric & Manufacturing Company, Pittsburg, Pennsylvania.
Briggs & Stratton Company, Milwaukee, Wisconsin.
Holcomb & Hoke, Indianapolis, Indiana.
Stewart-Warner Speedometer Corporation, Chicago, Illinois.
Cutler-Hammer Manufacturing Company, Milwaukee, Wisconsin.
American Radiator Company, Buffalo, New York.
Link-Belt Company, Indianapolis, Indiana.
Doehler Die Castings Company, Brooklyn, New York.

TOXIC GAS EQUIPMENT

America entered the war more than two years after the Germans had made their first gas attack. In those intervening months, gas warfare had grown to be a science in itself, requiring special organizations with each army to handle it.

The employment of toxic gas had developed in several directions. The attack by the Germans upon the maskless Canadians at Ypres had been in the form of a gas cloud from projectors, these being pressure tanks with nozzle outlets. For some time the Germans continued the use of gas solely by this method. Retaliation by the Allies followed promptly. But the employment of gas-cloud attacks involved great labor of preparation and was absolutely dependent upon certain combinations of weather conditions. Therefore the launching of a gas attack in this form could not be synchronized with other tactical operations; and the Allies were compelled to evolve other means of throwing toxic gases. This they did by enclosing the gas in shell shot from the big guns of the artillery and in grenades thrown by hand from the trenches; also—most effectively of all—by the agency of an ingenious invention of the British known as the Livens projector.

The Livens projector was deadly in its effect, for it could throw gas bombs, or drums, into the enemy's ranks suddenly and in great quantity. It is notable that, although the British used this device with great success throughout much of the latter period of the war, and though the French and Americans also adopted it and used it freely, the Germans were never able to discover what the device was that threw such havoc into their ranks, nor were they ever able to produce anything similar to it. The Livens projector remained a deep secret until the close of hostilities, and both the government offices in Washington, where the design was adapted to American manufacture, and the American plants producing the parts were always closely guarded against enemy espionage.

Without going into details of the construction of the Livens projector, it may be said that it was usually fired by electricity in sets of twenty-five or multiples thereof. The drums, which

were of cylindrical shell about twenty-four inches long and eight inches in diameter, were ejected from long steel tubes, or barrels, buried in the ground and resting against pressed-steel base plates. At the throwing of an electric switch a veritable rain of the big shell, as many as 2,500 of them sometimes, with their lethal contents, would come hurtling down upon the enemy. The Livens projectors could throw their gas drums nearly a mile.

The projector was entirely a new type of munition for our manufacturers to handle. The Trench Warfare Section of the Ordnance Department took up the matter late in 1917 and by May, 1918, had designed the weapon for home manufacture. Early in June the contracts were allotted for barrels and gas drums, or shell. The production of barrels was exclusively in the hands of the National Tube Company of Pittsburg, Pennsylvania, and the Harrisburg Pipe & Pipe Bending Company of Harrisburg, Pennsylvania. These companies reached the production stage in August, 1918, and completed about 63,000 barrels before the armistice was signed. Their respective plants reached a daily production rate of approximately 600 barrels.

Somewhat later in the spring of 1918 the contracts were closed for the base plates on which the barrels rest when ready for firing, for muzzle covers, and for various other accessories. Over 100,000 base plates were produced by the Gier Pressed Steel Company, of Lansing, Michigan, and the American Pulley Company, of Philadelphia, Pennsylvania. The Perkins-Campbell Company, of Philadelphia, built the muzzle covers—66,180 of them. Cartridge cases were manufactured by Art Metal (Inc.), of Newark, New Jersey, and the Russakov Can Company, of Chicago, the former producing 288,838 and the latter 47,511. The Ensign-Bickford Company, of Simsbury, Connecticut, produced 334,300 fuses for Livens shell; the Artillery Fuse Company, of Wilmington, Delaware, assembled 26,000 firing mechanisms; the E. I. DuPont Company, at its Pompton Lakes (New Jersey) plant, manufactured 20,000 detonators; 487,350 detonators were produced by the Ætna Explosives Company, at Port Ewen, New York; and

Photo from Ordnance Department

VERTICAL CROSS SECTION OF LIVENS PROJECTOR IN GROUND READY FOR FIRING

Photo from H. C. Dodge, Inc.

MANUFACTURING TRENCH MORTAR SHELL

Photo by Signal Corps

6-INCH TRENCH MORTAR

Photo by Signal Corps

FIRING 3-INCH MORTAR

the American Can Company, at Lowell, Massachusetts, assembled 256,231 firing mechanisms. Shear wire pistols were used in the operation of the Livens projector. The Edison Phonograph Company, of Orange, New Jersey, produced 181,900 of these, and the Artillery Fuse Company, of Wilmington, Delaware, 11,747. The adapters and boosters of the shell were all built by the John Thompson Press Company, of New York. The Waterbury Brass Goods Company, of Waterbury, Connecticut, made the fuse casing. Adapters and boosters to the number of 334,500 were turned out by the former, and 299,900 fuse casings by the latter.

The manufacture of gas drums for the projectors was delayed for some time because of difficulties in welding certain parts of the drums. Acetylene and arc welding processes were tried out, and a good many shell were made by such welding; but the lack of expert welders for these processes, and the rejections of shell due to leakage in the welded joints, caused the manufacturer to turn to fire welding, the process for which had been developed by the Air-tight Steel Tank Company, of Pittsburg, Pennsylvania. At the time the armistice was signed the welding problem had been overcome and the production was going forward at a rate to meet the requirements of the expected fighting in the spring of 1919. The shell delivered were produced as follows: By the Federal Pressed Steel Company, of Milwaukee, Wisconsin, 5,609; by the Pressed Steel Tank Company, also of Milwaukee, 20,536; by the Air-tight Steel Tank Company, of Pittsburg, Pennsylvania, 600; by the National Tube Company, of Pittsburg, 27,098; by the Truscon Steel Company, of Youngstown, Ohio, 19,880. The entire Livens shell program, as it existed in November, 1918, called for the production of 334,000 shell.

TRENCH MORTARS

THE production of trench mortars was not only an important part of our ordnance program, but it was also an undertaking absolutely new to American experience. Not only did we have to produce mortars, but we had to supply them with shell in

great quantities—in itself an enterprise of no mean proportions.

Some seven different types of mortars were in use when we came into the war. Our ordnance program contemplated the manufacture of all seven, but we actually succeeded in bringing only four types into production. These four were the British Newton-Stokes mortars of the 3-inch, 4-inch, and 6-inch calibers, and the French 240-millimeter mortar, which had also been adopted by the British. As usual in the adoption of foreign devices, we had to redesign these weapons to make them adaptable to American shop methods. We encountered much difficulty throughout the job, largely because of the insufficiency of the information furnished from abroad, and because, in spite of this handicap, we had to produce mortars and ammunition that would be interchangeable with French and British munitions stocks.

The first one of these weapons which we took up for production here was the 3-inch Newton-Stokes. The first contract for the manufacture of mortars of this size was placed with the Crane Company, of Chicago, on November 8, 1917, for 1,830 mortars. This concern at once arranged with the Ohio Seamless Tube Company, of Shelby, Ohio, for the drawing of steel tubes for the mortar barrels. The latter concern, however, was already handling large contracts for the Navy and for the aircraft program, and these operations took priority over the mortar contracts. But the Crane Company took advantage of the interim to build the accessories for the weapons—the tripods, clinometers, base plates, and tool boxes. In the spring of 1918 the company received the first barrel tubes and began producing completed weapons. But when these mortars were sent to the proving ground, the test-firing deformed the barrels and broke the metal bases. Finally it was decided that the propelling explosive used was not a suitable one for the purpose. Another was substituted. The new propellant permitted as great a range of fire without damage to the mortar in firing.

The Crane Company was eventually able to reach a production of thirty-three of the 3-inch mortars a day, and up

to December 5, 1918, it had built 1,803 completed weapons, together with the necessary tools and spare parts. In the early fall of 1918 an additional contract for 677 of these mortars was placed with the Crane Company and another for 2,000 mortars of this size with the International Harvester Company of Chicago. Neither of the two latter contracts ever came to the production stage.

A few days after the original contract for 3-inch mortars was let, the Trench Warfare Section took up the matter of producing ammunition for these weapons. Two sorts of shell were to be required—live shell filled with high explosive and practice shell made of malleable iron. The original program, adopted in November, 1917, called for the production of 5,342,000 live shell for the 3-inch mortars and 1,500,000 practice shell.

The plan was adopted of building these shell of lap-welded 3-inch steel tubing, cut into proper lengths. The contracts for the finished machined and assembled shell were placed with the General Motors Corporation at its Saginaw (Michigan) plant, with H. C. Dodge (Inc.), at South Boston, Massachusetts, and with the Metropolitan Engineering Company, of Brooklyn, New York. In order to facilitate production, the Government agreed to furnish the steel tubing. For this purpose it ordered from the National Tube Company, of Pittsburg, Pennsylvania, 1,618,929 pieces of steel tubing, each eleven inches in length, and from the Allegheny Steel Company, at Brackenridge, Pennsylvania, 2,332,319 running feet of tubing. These tube contracts were filled by the early spring of 1918. The railroad congestion of February and March, 1918, held up the delivery of tubing, but the assembly plants utilized the time in tooling up for the future production. All the plants thereafter soon reached a quantity production, the General Motors Corporation in particular tuning up its shop system until it was able to reach a maximum daily production, in a ten-hour shift, of 35,618 completed shell.

The casting of malleable iron bodies for the practice shell of this caliber was turned over to the Erie Malleable Iron Com-

pany, of Erie, Pennsylvania, and to the National Malleable Castings Company, with plants at Cleveland, Chicago, Indianapolis, and Toledo. The former concern cast 196,673 bodies and the latter 1,015,005. The Gorham Manufacturing Company, of Providence, Rhode Island; the Standard Parts Company, of Cleveland, Ohio; and the New Process Gear Corporation, of Syracuse, New York, machined and assembled the practice shell. When the armistice was declared, these three contracts were approximately seven-tenths complete.

We were dissatisfied with our 3-inch shell, for the reason that they tumbled in air and were visible to the eye. The French had developed a mortar shell on the streamline principle which was invisible in flight and had twice the range of ours. Had the war continued, the Trench Warfare Section would have produced streamline shell for mortars.

The second mortar project undertaken was the manufacture of the 240-millimeter weapon. This was the largest mortar which we produced, its barrel having a diameter of approximately ten inches. It proved to be one of the toughest nuts to crack in the whole mortar undertaking. The British designs of this French weapon we found to be quite unsuited to our factory methods, and for the sake of expediency we frequently modified them in the course of the development. The total contracts called for the production of 938 mortars.

It was obvious that the manufacture of this and of other larger mortars would fall into three phases. The forging of barrels, breechblocks, and breech slides was a separate type of work, and we allotted the contracts for this work to the Standard Forging Company of Indiana Harbor, Indiana. The machining of these parts to the fine dimensions required by the design was an entirely separate phase of manufacturing, and we placed this work with the American Laundry Machine Company of Cincinnati. Still a third class of work was the assembling of the completed mortars, and this contract went to the David Lupton Sons Company of Philadelphia, who also engaged to manufacture the metal and timber bases and firing mechanisms. These big mortars had to have mobile mountings,

and the contract for the mortar carts we placed with the International Harvester Company of Chicago. These contracts were signed in December, 1917.

The Lupton plant had difficulty in securing the heavy machinery needed for this and for other mortar contracts, its machinery being held up by the freight congestion. Early in 1918 the American Expeditionary Forces advised us to redesign the 240-millimeter mortar to give it a stronger barrel. Consequently all work was stopped until this could be done. The first mortars of the new design to be tested were still unsatisfactory with respect to the strength of the barrels; and the Standard Forging Company urged that nickel steel be substituted for basic open-hearth steel as the material for the barrels. This change proved to be justified.

There was also trouble at the shops of the American Laundry Machine Company, its equipment not having the precision to do machining of the type required in these weapons. Accordingly a new machining contract was made with the Symington-Anderson Company of Rochester, New York, which concern was eventually able to reach a production of twenty machined barrels per week.

In all, we produced twenty-four of the 240-millimeter mortars in this country. Certain of the parts were manufactured up to the total requirements of the contracts, but others were not built in such numbers. The International Harvester Company built all the 999 carts ordered.

The production of shell for these big mortars was another difficult undertaking. After consultation with manufacturers we designed shell of two different types. One of these was a shell of pressed plates welded together longitudinally; and a contract for the production of 283,096 of these was placed with the Metropolitan Engineering Company. The other was of two steel hemispheres welded together. The Michigan Stamping Company, of Detroit, undertook to build 50,000 of these. These shell contracts were placed in December, 1917. The Michigan Stamping Company had to wait five months before it could secure and install its complete equipment of

machinery. It was September before all the difficulties in the Detroit plant's project could be overcome and quantity production started. The concern eventually, before and after the signing of the armistice, built 9,185 shell of this type at a maximum rate of fifty-six a day.

Greater promise seemed to attend the Metropolitan Engineering Company's project to build shell of pressed-out plates, electrically welded. The Government undertook to furnish the steel plates for this work and secured from the American Rolling Mills Company of Middletown, Ohio, a total production of 6,757 tons of them. The Metropolitan Engineering Company had great difficulty in perfecting a proper welding process; and the concern lost a great deal of money on the contract, yet cheerfully continued its development without prospect of recompense, in order that we might have in this country the knowledge of how to build such shell. In all, including production after the armistice was signed, the Metropolitan Engineering Company built 136,189 shell bodies of this size, at a maximum rate of 987 a day.

During the summer of 1918 a single-piece shell body of the 240-millimeter size, produced by a deep-drawing process, was worked out. A contract for 125,000 such bodies was given to the Ireland-Matthews Manufacturing Company of Detroit, Michigan. The armistice brought this contract to an end before it had produced any shell of this new and most promising type.

Early in 1918 we received the first samples of the 6-inch trench mortar. By April all the plans were ready for American production. Again this work was divided by types. The National Tube Company of Pittsburg contracted to make 510 rough forgings of mortar barrels at its Christy Park plant. The Symington-Anderson Company undertook to machine these barrels. The David Lupton Sons Company agreed to assemble the mortars, as well as to produce the metal and timber bases for them. The first machined barrels reached the Lupton plant in June and found bases ready for them. But while assembling was in progress the American Expeditionary

Forces cabled that the British producers of mortars had changed their designs, and that we must suspend our manufacture until we could adopt the changes. It was some weeks later when the altered plans reached us; nevertheless, we were able to make good our original promise to deliver forty-eight 6-inch Newton-Stokes mortars at the port of embarkation in October, 1918.

Meanwhile we had increased the contracts by an additional requirement of 1,577 mortars of this size. The National Tube Company eventually reached a maximum daily production of sixty barrel forgings. The Symington-Anderson Company machined the barrels finally at the rate of thirty-three a day. As many as eleven proof-fired guns a day came from the David Lupton Sons Company.

An interesting fact in connection with the production of shell for the 6-inch mortars is that they were built principally by American makers of stoves. The 6-inch mortar shell bodies, being of cast iron instead of steel, were adaptable to manufacture in stove works. Each shell weighed forty pounds without its explosive charge. Such shell were used at the front for heavy demolition purposes.

The contracts for these shell were placed in March, 1918. The Trench Warfare Section was immediately called upon to secure favorable priority for the pig iron required for this purpose. The various stove works did not have the necessary machinery for building the shell, and in each a special equipment had to be built. At the tests the first castings which came through the foundry were found to leak, and this setback prescribed further experiments in the design, holding up production until July, 1918.

Because of the many troubles encountered in this work, the various stove makers formed, in the summer of 1918, an association which they called the Six-inch Trench-mortar Shell Manufacturers' Association. This association held monthly meetings, and its members visited the various plants where shell castings were being made. The United States Radiator Corporation, the Foster-Merriam Company, and the Michigan

Stove Company were especially active in improving methods for making these shell.

The various concerns which produced 6-inch mortar shell and the amounts turned out were as follows:

Foster-Merriam Company, Meriden, Connecticut	33,959
U. S. Radiator Corporation, Detroit, Michigan	240,700
Globe Stove & Range Company, Kokomo, Indiana	17,460
Rathbone, Sard & Company, Albany, New York	97,114
Michigan Stove Company, Detroit, Michigan	100,000

The concerns named below, shortly before the armistice was signed, received contracts for the production of 6-inch mortar shell, orders ranging in quantity from 50,000 to 150,000, but none of these concerns started production:

William Crane Company, Jersey City, New Jersey.
Frontier Iron Works, Buffalo, New York.
Henry E. Pridmore (Inc.), Chicago, Illinois.
Best Foundry Company, Bedford, Ohio.
McCord & Company, Chicago, Illinois.

It was not until July, 1918, that the plans were ready for the 4-inch Newton-Stokes trench mortars. The American Expeditionary Forces estimated that they would require 480 of these weapons. A total of 500 drawn barrel tubes was ordered from the Ohio Seamless Tube Company of Shelby, Ohio. This concern was able to ship one-fifth of its order within ten days after receiving it. The barrels were sent to the Rock Island Arsenal for machining. The Crane Company of Chicago held the contract for building the bases, tripods, spare parts, and tools, and also for the assembling of the completed mortars. This factory was already equipped with tools for this work, since it had been building similar parts for 3-inch mortars; in August, almost within a month of receiving the contract, the Crane Company was producing completed 4-inch mortars and sending them to the Rock Island Arsenal for proof firing. The Ohio Seamless Tube Company reached a high daily production of eighty-three barrel forgings; the Rock Island Arse-

Photo from Ordnance Department

6-INCH TRENCH MORTAR SHELL

Photo from Ordnance Department

240-MILLIMETER TRENCH MORTAR WITH SHELL READY FOR ACTION

Photo from Crane Company

WAR PLANT ENGAGED IN MANUFACTURE OF TRENCH MORTARS

Photo from David Lupton Sons Company

ASSEMBLING LARGE TRENCH MORTARS

nal, ten machined barrels a day; and the Crane Company, nineteen assembled mortars a day.

We planned to build only smoke shell and gas shell for the 4-inch mortars. Large contracts for various parts of these shell were placed, and the enterprise was gaining great size, when the armistice was declared; but no finished smoke shell, and only a few gas shell, for 4-inch trench mortars had been produced. The contracts for the smoke shell were let in October, 1918, and work had not gone further than the procurement of raw material when the armistice came. A large number of contractors expected to produce parts for the 4-inch gas shell, and considerable quantities of the raw materials were actually produced; but only one of the machining and assembling contractors, the Paige-Detroit Motor Car Company, actually completed any of these shell, and production at this plant did not start until December 5, 1918.

Production of Trench Mortars and Their Ammunition

Trench Mortars

Size	*Completions to Nov. 11, 1918*	*Completions to Feb. 1, 1919*	*Shipped overseas*
3-inch	1,609	1,830	843
4-inch	444	778	...
6-inch	368	500	48
240-millimeter (9.45 inches)	29	30	...

Trench-Mortar Shell

Kind	*Completions to Nov. 11, 1918 (unloaded)*	*Completions to Feb. 1, 1919 (unloaded)*	*Shipped overseas (loaded)*
	Rounds	*Rounds*	*Rounds*
3-inch live	3,136,275	3,741,237	157,785
3-inch practice	607,178	782,340	......
4-inch gas	......	212	......
4-inch smoke	......	......	......
6-inch live	292,882	492,404	......
240-millimeter (9.45 inches)	67,829	131,124	......

TOXIC GAS SETS

ANOTHER extensive project in the trench-warfare program was the manufacture of the so-called toxic gas sets. Each set consisted of a one-man portable cylinder equipped with a nozzle and a firing mechanism. It was ready for firing as soon as placed in position.

In August, 1918, the toxic-gas-set project was taken up by the Trench Warfare Section. Contracts for cylinders were awarded to the Ireland-Matthews Manufacturing Company, of Detroit, Michigan, which produced 13,642 cylinders, and to the American Car & Foundry Company, at its Milton, Pennsylvania, plant, which turned out 11,046 cylinders.

The Pittsburg Reinforcing, Brazing & Machine Company produced 9,765 valves for the cylinders in two months after receiving the contract. The Yale & Towne Manufacturing Company, of Stamford, Connecticut, which received the contract for nozzles on September 5, 1918, manufactured 20,501 of them before the armistice was signed; and J. N. Smith & Company, of Detroit, Michigan, who did not receive their contract until September 26, built 3,252 nozzles before the fighting stopped. The Liquid Carbonic Company, of Chicago, and the Ruud Manufacturing Company, of Pittsburg, had the contracts for the firing mechanism; but none of these was produced, because at the time the armistice was signed the firing mixture to be used with the cylinders had not been developed.

In connection with the production of materials for gas warfare the Ordnance Department also designed several types of containers for the shipment of poison gas, these including not only the portable cylinders, but also larger tanks and even tank cars.

PYROTECHNICS

A FEW years ago, when we allowed the adventurous American boy to blow off his fingers and hands by the indiscriminate use of explosives in celebrating the nation's birthday, we had an extensive fireworks industry in this country. But the spread of the Sane-Fourth reform had virtually killed this manufacture, so that when we entered the war there were only three or

four plants in the United States making fireworks. These concerns kept the trade secrets closely guarded. As we approached the brink of hostilities it was evident that we should have to build up a large production capacity for the pyrotechnics demanded by the various new types of fighting which had sprung into existence since 1914. Fireworks were extensively used, principally for signaling at night and as an aid to aviators in the dark.

One of the men to foresee this need was Lewis Nixon, who had long been in the public eye and was known especially for his advocacy of an American merchant marine. He organized a pyrotechnics concern known as the Nixon Fulgent Products Company, built a plant at Brunswick, New Jersey, and was ready to talk business with the Government when the war began. Also there had long been in existence that perennial delight of children and adults alike, known as Pain's Fireworks, the spectacular exhibitions of which are familiar to most city dwellers in the United States. This concern had its own manufacturing plant, which was ready to expand to meet government war requirements. In addition, two other concerns of the formerly declining industry were ready to increase their facilities and produce pyrotechnics for war purposes. These were the Unexcelled Manufacturing Company, of New York, and the National Fireworks Company, of West Hanover, Massachusetts. The four concerns proved to be able to meet every war requirement we had.

Before the war some few military pyrotechnics had been procured by the Signal Corps, the Coast Artillery, the Engineer Corps, and also by the Navy; but on September 27, 1917, the design of all army pyrotechnics was centralized in the Trench Warfare Section. Much experimentation was necessary before specifications could be prepared, for the entire fire-signaling field had long been in confusion. We had made our own designs and were proceeding with production in the spring of 1918, when the American Expeditionary Forces made the positive recommendation that the entire French program of pyrotechnics be adopted by the United States. This meant a

fresh start in the business, but nevertheless pyrotechnic devices were developed to meet all our needs. These devices included signal rockets, parachute rockets, signal pistols and their ammunition, position and signal lights, flares, smoke torches, and lights to be thrown by the V. B. discharger, the French device attached to the end of the rifle in which a rifle grenade fits.

At the outset of our efforts we started to build signal rockets, position lights, rifle lights, signal lights, and lights for use with the Very signal pistol. The Very signal pistol which we adopted first had the caliber of a 10-gauge shotgun, and its cartridges resembled shotgun shells in appearance, although they contained Roman-candle balls of various colors instead of leaden shot. The orders from abroad in the spring of 1918 changed the caliber of the Very pistol to 25 millimeters and brought into our requirements some sixteen different styles of star and parachute cartridges. In addition to these, there were required about twenty styles of star and parachute cartridges for the French V. B. discharger. The recommendations from France brought in thirteen new styles of signal rockets, as well as smoke torches, wing-tip flares for airplanes, parachute flares for lighting the ground under bombing airplanes, and also twelve styles of cartridges for a new 35-millimeter Very pistol for the use of aviators.

After we received these instructions there was great uncertainty here as to the quantity of each item that should be produced; and this matter was not settled until August 5, 1918, when an enormous program of requirements was issued. At first it seemed that the Government itself must build new factories to provide for these needs, but a careful examination showed that the existing facilities could be expanded to take care of the production. The placing of contracts in this undertaking was under way when the armistice stopped the work.

The table subjoined to this chapter indicates the size of the pyrotechnic undertaking and also what was accomplished. All this production came from the plants of the four companies which have been named. In addition to the fireworks them-

selves, accessories were produced by a number of other concerns. The Japan Paper Company, New York City, manufactured and imported from Japan approximately 3,000,000 paper parachutes. The Remington Arms Company, New Haven, Connecticut, built about 2,500,000 10-gauge signal-pistol cartridges, minus the stars they contained. The Empire Art Metal Company, College Point, New York, produced nearly 2,000,000 Very pistol cartridge cases. The Winchester Repeating Arms Company, Bridgeport, Connecticut, supplied nearly 5,000,000 primers for these cartridges. Rose Brothers & Company, Lancaster, Pennsylvania, produced 65,600 silk parachutes for Very cartridges. Cheney Brothers, South Manchester, Connecticut; D. G. Dery (Inc.), Allentown, Pennsylvania; Stehli Silk Corporation, New York City; Sauquoit Silk Company, Philadelphia; Lewis Roessel & Company, Hazleton, Pennsylvania; Schwarzenback-Huber Company, New York City; and the Duplane Silk Corporation, Hazleton, Pennsylvania, produced a total of 1,231,728 yards of silk for parachutes to float airplane flares. The parachutes themselves for the airplane flares, a total of 28,570, were manufactured by the Duplane Silk Corporation; Folmer-Clogg Company, Lancaster, Pennsylvania; and Jacob Gerhardt Company, Hazleton, Pennsylvania. The Edward G. Budd Manufacturing Company, Philadelphia, built 41,020 metal cases for the airplane flares.

We also contracted for the production of many thousands of Very signal pistols. Before the original program was canceled the Remington Arms Company had produced 24,460 of the 10-gauge pistols in contracts calling for a total output of 35,000. In August, 1918, we let contracts for 135,000 of the 25-millimeter pistols and for approximately 30,000 of the 35-millimeter pistols. The A. H. Fox Gun Company completed 4,193 of the smaller pistols and the Scott & Fetzger Machine Company turned out 7,750 of them. Other concerns which had taken contracts, but had not come into production when the armistice was signed, were the National Tool &

Manufacturing Company, the Doehler Die Castings Company, the Hammond Typewriter Company, and Parker Brothers.

Considerable experimental work of an interesting sort was carried out, looking toward the development of incendiary devices. Three types of flame projectors, flaming bayonets, an airplane destroyer, incendiary darts, and the smoke knapsack were among the projects undertaken. Owing in large measure to changes in requirements by the American Expeditionary Forces, none of these devices was actually turned out on any considerable scale.

Production of Pyrotechnics

Articles	*Ordered*	*Completed to Nov. 8, 1918*	*Completed to Feb. 1, 1919*
Signal rockets . . .	615,000	437,101	544,355
Position lights . . .	2,072,000	1,187,532	1,670,070
Rifle lights	55,000	55,000	55,000
Signal lights	3,110,000	2,661,008	2,710,268
V. B. cartridges . . .	1,215,000	110,000	673,200
Very cartridges, 25-millimeter	300,000	......	......
Smoke torches . . .	500,000	31,000	188,102
Wing-tip flares . . .	112,000	70,000	100,865
Airplane flares . . .	50,083	2,100	8,000

CHAPTER XV

MISCELLANEOUS ORDNANCE EQUIPMENT

THE miscellaneous ordnance equipment of the American soldier in the recent war,—that is, articles which he carried with him and which added to his comfort, his safety, or his efficiency as a fighter,—though in many respects identical with the equipment used by our troops for many years, contained several novelties.

Among these were helmets and armor. There is a widespread notion that helmets and body armor passed away with the invention of gunpowder, and because of that invention. This notion is not at all true. Body armor came to its highest development long after gunpowder was in common use in war. The sixteenth century witnessed the most extensive use of armor. At that time guns and pistols formed an important part of the equipment of every army, and even a weapon which is generally fancied to be ultramodern, the revolver, had been invented. The fact is that not gunpowder, but tactics, caused the decline of armor. Not that armor was unable to stop many types of projectiles fired from guns, but that its weight hampered swift maneuvering, caused it to be laid aside by the soldier. The decline of armor may be said to date from the Thirty Years' War. The armies in that period, and particularly the army of the Swedes, began making long marches for surprise attacks, and the body armor of the troops was found to be a hindrance in such tactics. Thereafter armor went out of fashion.

Yet it never completely disappeared in warfare. General Rochambeau is said to have worn body armor at the siege of Yorktown. Great numbers of corselets and headpieces were worn in the Napoleonic wars. The corselet which John Paul Jones wore in his fight with the *Serapis* is preserved at the

Metropolitan Museum of Art in New York. The Japanese Army was mailed with good armor as late as 1870. Breastplates were worn to some extent in the Civil War in the United States, and an armor factory was actually established at New Haven, Connecticut, about 1862. In the museum at Richmond, Virginia, is an equipment of armor taken from a dead soldier in one of the trenches at the siege of that city. There was a limited use of armor in the Franco-Prussian War. Some of the Japanese troops carried shields at Port Arthur. Helmets were worn in the Boer War. A notorious Australian bandit in the eighties for a long time defied armed posses to capture him, because he wore armor and could stand off entire squads of policemen firing at him with Martini rifles at close range.

It can not be said, then, that armor, in coming into use again in the Great War, was resurrected; it was merely revived. The war against Germany, in its static condition during most of the four-year period, was one in which armor could profitably be used. The opportunity could scarcely be overlooked, and indeed it was not. Everybody knows of the helmets that were in general use; body armor itself was coming into favor again, and in all probability only the welcome, but unexpected, end of hostilities prevented it from becoming once more an important part of the equipment of a soldier.

As a consequence of the attenuated, but persistent, use of armor by soldiers during the past two centuries and of the demand of the aristocratic for helmets and armor as ornaments, the armorer's trade had been kept alive from the days of Gustavus Adolphus to the present. The war efforts of the United States in 1917 and 1918 demanded a wide range of human talents and special callings; but surely the utmost extension of the bizarre seemed to be reached when, in the early days of our undertaking, the Engineering Division of the Ordnance Department sought the services of expert armorers. Through the advice of the National Research Council, which had established a committee of armor experts, the Ordnance Department commissioned in its service Major Bashford Dean, a lifelong specialist in armor, curator in the Metro-

politan Museum of Art, an institution which, learning of the need, at once placed at the Government's disposal its wonderful specimens of authentic armor, its armor repair shop, where models could at once be made, and the services of Major Dean's assistant there, whom he had brought from France—Daniel Tachaux, one of the few surviving armorers who had inherited lineally his technical mastery of the ancient craft.

There were but two nations in the World War which went to the Middle Ages for ideas of protective armor—ourselves and Germany. The Germans, who applied science to almost every phase of warfare, did not neglect it here. Germany early consulted her experts on ancient armor and worked out their suggestions. The German helmet used in the trenches was undoubtedly superior to any other helmet given a practical use.

The first helmets to be used in the Great War were of French manufacture. They were designed by General Adrien, and 2,000,000 of them were manufactured and issued to the French Army. These helmets were the product of hasty pioneer work, but the fact that they saved from 2 to 5 per cent of the normal casualties of such a war as was being fought at once impelled the other belligerents to adopt the idea. Great Britain, spurred by the necessity of quickly producing a helmet in quantity, designed the helmet most simple to manufacture, one which could be pressed out of cold metal.

When America entered the war she had, naturally, no distinctive helmet; and the English type, being easiest to make, was adopted to fill the gap until we could design a more efficient one ourselves. Four hundred thousand British helmets were bought in England and issued to the vanguard of the American Expeditionary Forces. Our men wore them, became accustomed to them, and came to feel that they were the badge of English-speaking troops. The British helmet thus became a habit with our men, and one difficult to change—a fact which militated against the popularity of the more advanced and scientific models which we were to bring out.

Now, the British helmet possessed some notable defects. It did not afford a maximum of protective area. The center of

gravity was not so placed as to keep the helmet from wobbling. Its lining was uncomfortable and disregarded the anatomy of the head. It was vulnerable at the concave surface where bowl and brim joined. It is not an astonishing circumstance that some of the earlier helmets worn by the men-at-arms of the days of knighthood possessed certain of these same defects—notably, they were top-heavy and uncomfortable. Only by centuries of constant application and improvement were the armorers of the Middle Ages able to produce helmets which overcame these defects and which embodied all the principles of defense and strength which science could put into them. The best medieval helmets stand at the summit of the art. It was the constant aim of the modern specialist, aided by the facilities of the twentieth-century industries, to produce helmets as perfect technically as those rare models which are the pride of museums and collectors.

Certainly in one respect we had the advantage of the ancients: we had at our disposal the modern alloy-steels of great resistance. An alloy of this kind, with a thickness of .036 of an inch, will stop a jacketed automatic pistol ball, .45 caliber, traveling at the rate of 600 feet a second, fired from a distance of ten feet. This was important, not only because it facilitated helmet production, but because it led to the inference that body armor of such steel might still be profitably used. The records of the hospitals in France show that seven or eight of every ten wounded soldiers were wounded by fragments of shell and other missiles which even thin armor plate would have kept out. The German troops used body armor in large numbers, each set weighing from nineteen to twenty-four pounds. In this country we believed it possible to produce body armor which would not be difficult to carry and which would resist the impact of a machine gun bullet at fairly close range.

The production of helmets, however, was our first concern; and in order to be sure of a sufficient quantity of these protective headpieces, we adopted the British model for production in the United States and went ahead with it on a large scale.

For the metal, we adopted, after much experimentation, a steel alloy with a high percentage of manganese. This was practically the same as the steel of the British helmet. Its chief advantages were that it was easy to work in the metal presses in existence and that it required no further tempering after leaving the stamping presses. Its hardness, however, wore away the stamping tools much more quickly than ordinary steel sheets would have done.

We adopted, then, the British helmet design and, substantially, its metal; but we originated our own lining. This was woven of cotton twine in meshes three-eighths of an inch square. This web, fitting tightly upon the wearer's head, evenly distributed the weight of the two-pound helmet, and in the same way distributed the force of any blow upon the helmet. The netting, together with small pieces of rubber around the edge of the lining, kept the helmet away from the head, so that even a rather large dent could not reach the wearer's skull.

It is an interesting fact that the linings for the American helmets were produced by concerns whose ordinary business was the manufacture of shoes. Ten of these companies took such contracts. Steel for the helmets was rolled by the American Sheet & Tin Plate Company. The helmets were pressed and stamped into shape by seven companies which had done similar work before the war. These were:

Contractor	*Delivered*
Edward G. Budd Manufacturing Company, Philadelphia	1,150,755
Sparks-Withington Company, Jackson, Michigan	473,469
Crosby Company, Buffalo, New York	469,968
Bossett Corporation, Utica, New York	116,735
Columbian Enameling & Stamping Company, Terre Haute, Indiana	268,850
Worcester Pressed Steel Company, Worcester, Massachusetts	193,840
Benjamin Electric Company, Des Plaines, Illinois	33,600
Total	2,707,217

The metal helmets and the woven linings were delivered to the plant of the Ford Motor Company at Philadelphia, where they were painted and assembled. The helmets were painted in the olive-drab shade for protective coloring. Though such objects could not be discerned at a great distance on dull days, in bright weather their rounded surfaces might catch and reflect sunbeams and betray the positions of their wearers. To guard against this, as soon as the helmets were treated to a first coat of paint fine sawdust was blown upon the wet surface. When this had dried, another coat of paint was applied; and thus a nonreflecting, gritty surface was produced.

We began to receive substantial quantities of finished helmets by the end of November of the first year of the war. On February 17, 1918, practically 700,000 had been shipped abroad or were ready for shipment at the ports of embarkation. Later in the spring of 1918, when we began sending men to France much beyond our earlier expectations, the orders for helmets were greatly expanded. In July the total orders reached 3,000,000, in August 6,000,000, and in September 7,000,000. This would give us enough to meet all requirements until June, 1919. When the armistice was signed the factories were producing more than 100,000 helmets every four days, and were rapidly approaching the time when their daily output would be 60,000. The Government canceled all helmet contracts as soon as the fighting ceased, having received up to that time a total of 2,700,000.

While this manufacture was going on we were developing helmets of our own. Major Dean went to France to collect information dealing with the actual needs of the service and to present numerous experimental models of helmets for the comment and criticism of the General Staff. Several of these models were accepted for manufacture here in experimental lots. In all, we developed four models which seemed to have merits sufficient to recommend their adoption. The first distinctive American helmet was known as model No. 2. The Ford Company at Detroit pressed about 1,200 of these helmets. The helmet, however, was similar in appearance to the

German helmet, and for that reason was disapproved by the American Expeditionary Forces. Helmet Model No. 3 was of a deep-bowl type, but it was rejected when the Hale & Kilburn Company, of Philadelphia, after a great deal of experimentation, found that it was too deep for successful manufacture by pressing. Model No. 4 was designed by the master armorer of the Metropolitan Museum of Art. It was also found too difficult to manufacture.

Helmet No. 5 was strongly recommended by American experts, but was not accepted by the General Staff. It was designed by the armor committee at the Metropolitan Museum of Art, in conjunction with the Engineering Division of the Ordnance Department. Hale & Kilburn undertook to manufacture these helmets, which were to be painted, assembled, and packed by the Ford Motor Company at its Philadelphia plant. Various component parts of the helmet were sublet in experimental quantities to numerous manufacturers. The No. 5 helmet, complete, weighed two pounds, six and one-half ounces. It combined the virtues of several types of helmets. It gave a maximum of protection for its weight. It was comparatively easy to produce. This helmet, with slight variations, was later adopted as the standard helmet of the Swiss Army. The latest German helmet, it is interesting to note, approximated its lines.

We also produced helmets for special services—one with a visor to protect machine gunners and snipers, and another, known as Model 14, for aviators, it being little heavier than the leather helmet which airmen wore in the war and twenty times as strong a defense for the head. A third special helmet, known as Model 15, was for operators of tanks. It was provided with a neck guard of padded silk to stop lead splash which might penetrate the turret of the tank. The Ordnance Department turned out twenty-five of these in ten days and sent them by courier to France for a test.

The Germans issued body armor only to troops holding exposed positions under heavy machine gun and rifle fire; but even such use was distinctly valuable, as was shown by cap-

tured German reports. The Engineering Division of the Ordnance Department developed a body defense which included a light front and a body plate, these together weighing nine and one-half pounds. One lot of 5,000 sets was manufactured by the Hale & Kilburn Company. The linings of these plates were of sponge rubber, and they were made by the Miller Rubber Company of Akron, Ohio. All these sets were shipped abroad for testing; but the report was not favorable, for the American soldier did not wish to be hampered with armor. He had learned to wear his helmet, but he had yet to be convinced of the practical value of body armor. We developed a heavy breastplate with thigh guards, weighing twenty-seven pounds, which stopped machine gun bullets at 150 yards. An experimental lot of these was completed in twenty-six days by the Mullins Manufacturing Company of Salem, Ohio. These were also shipped abroad for test. A few defenses for arms and legs were prepared which, although light in weight, would protect the wearer from an automatic-pistol ball at ten feet. About 70 per cent of the hospital cases in France were casualties caused by wounds in the arms and legs. These defenses, however, were rejected because they somewhat impeded the movements of the wearer.

Our development in armor also produced an aviator's chair weighing sixty pounds. Withstanding armor-piercing bullets fired at a distance of fifty yards, it would protect the pilot against injury from below and from the back. Since the piercing of the gas mask canister by a bullet might result in the death of the soldier by admitting gas directly into the breathing system of his mask, the Ordnance Department also designed an armored haversack for the gas mask and its canister, this haversack incidentally serving as a breast defense.

BAYONETS AND TRENCH KNIVES

ANOTHER large ordnance operation was the production of bayonets for the service rifles. The British bayonet had proved to be highly satisfactory in the war; and, since it was already designed to fit the Enfield rifle, which we had adopted for our

Photos from Metropolitan Museum of Art

AMERICAN ARMOR

TWO VIEWS OF AMERICAN EXPERIMENTAL HELMET

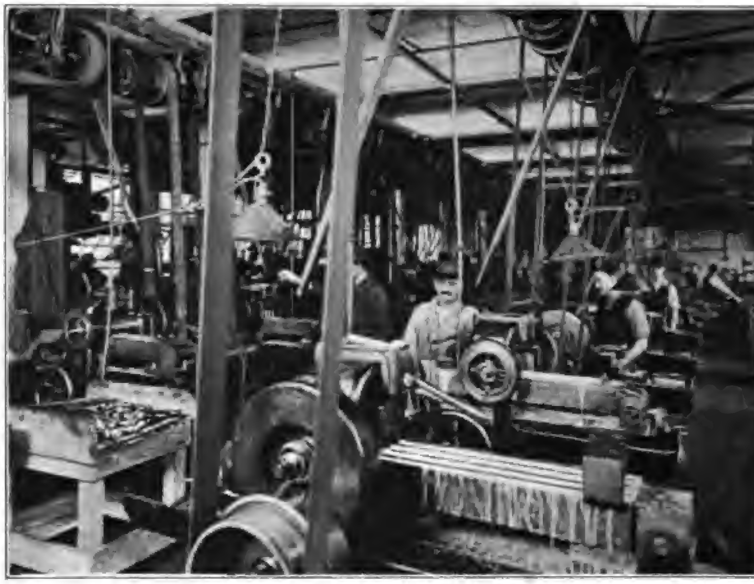


Photo from Landers, Frary & Clark

MANUFACTURING BAYONETS

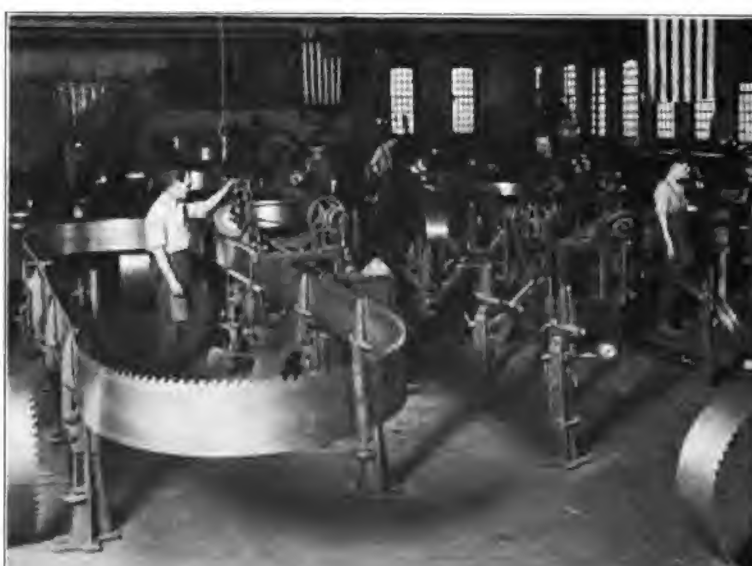


Photo by Signal Corps

MAKING TRENCH KNIVES

own, we took the British bayonet as it was and, with one slight alteration, set out to produce it in this country.

The Government found both the Remington Arms-Union Metallic Cartridge Company at its Bridgeport, Connecticut, works, and the Winchester Repeating Arms Company building these bayonets for the English Government. By 1917 Great Britain's demands were being well supplied by home manufacture, and we were able to buy approximately 545,500 bayonets which had already been manufactured for the British. The Ordnance Department at once started these two concerns on contracts for bayonets for the American Government, Remington with total orders for 2,820,803 bayonets and Winchester with orders for 672,500. Remington delivered, in all, 1,565,644 bayonets and Winchester 395,894—a total of 1,961,538.

The total production of 1917 rifles was about 2,520,000. These figures indicate that we were short over 500,000 bayonets at the time hostilities ceased; and as a matter of fact this shortage had already become acute, especially in the training camps. The bayonets had not come so rapidly as we had expected, because to produce them at the rate originally planned would have interfered with the more essential production of rifles by these same companies. Accordingly, in 1918 additional contracts for bayonets were made. Landers, Frary & Clark, of New Britain, Connecticut, engaged to manufacture 500,000 bayonets, and the National Motor Vehicle Company 255,000. These latter contracts were suspended after the armistice was signed. The additional orders had made it certain that there would be no bayonet shortage by the spring of 1919.

While this production was under way we were also manufacturing bayonets for the model 1903 Springfield rifle. The Springfield Armory produced 347,533 of these and the Rock Island Arsenal 36,800. In addition the Springfield Armory delivered 50,000 bayonet blades as spare parts.

We had to provide not only bayonets, but also their scabbards. The scabbard of the 1917 bayonet was of simple manufacture, and there were no difficulties in securing sufficient

quantities. The Jewell Belt Company delivered 1,810,675 of them; Graton & Knight delivered 1,669,581; and the Rock Island Arsenal produced 3,000. This gave us a total of approximately 3,480,000 scabbards, a quantity greatly in excess of the production of either bayonets or rifles.

A new weapon which had come into use during the Great War, as part of the soldier's individual equipment, was the trench knife. The question of making such knives was taken up by the Government with various manufacturers throughout the country. They were given a general idea of what was required and, in conjunction with the Ordnance Department, were requested to develop details. The design submitted by Henry Disston & Sons, of Philadelphia, received the most favorable consideration. This knife was manufactured and known as model 1917. It was a triangular blade nine inches long. The triangular blade was deemed the most efficient because of the ease with which it would pierce clothing and even leather. This knife, slightly changed in the handle and given a different guard to protect the user's knuckles, was known as model 1918. These knives were sent abroad in large quantities to be used by the American Expeditionary Forces. Landers, Frary & Clark produced 113,000 and the Oneida Community (Ltd.), Oneida, New York, 10,000.

On June 1, 1918, the American Expeditionary Forces made an exhaustive test in comparison of the various trench knives used abroad. The four knives tested were: United States, model 1917; Hughes; French; and British knuckle knife. These tests were made to determine the merits of the different knives in the following points: (a) serviceableness, or adaptability to use in conjunction with other weapons; (b) quickness in action; (c) likelihood of its dropping from the hand of a soldier knocked unconscious; (d) fitness for being carried in the hand while crawling; (e) possibility of its being knocked out of the hand; (f) weight, length, and shape of blade; and (g) shape of handle. It was found that the model 1917, although a satisfactory knife, could be improved. Therefore the trench knife known as Mark I was developed,

partly by the American Expeditionary Forces and partly by the Ordnance Engineering Division. This knife was entirely different from the model 1917, having a flat blade, a metal scabbard, and a cast-bronze handle. It was a combination of all the good points of all the knives used by the foreign armies. The Government placed orders for 1,232,780 of the new knives. Deliveries were to have begun in December, but before that time peace had come and the orders had been reduced to 119,424. The new model knives were to have been manufactured by A. A. Simons & Son, Dayton, Ohio; Henry Disston & Sons, Philadelphia; Landers, Frary & Clark, and the Oneida Community (Ltd.). All contracts were canceled except the one with Landers, Frary & Clark.

PERISCOPES, BELTS, ETC.

ANOTHER new article in the equipment of our soldiers was the trench periscope, a device which enabled a man to look over the edge of the trench without exposing himself to fire. The ordinary periscope was merely a wooden box two inches square and fifteen inches long, with an inclined mirror set at each end. Production was begun in October, 1917, by two companies, and 81,000 were delivered by the middle of January. In August, 1918, an additional lot of 60,000 was ordered, but the deliveries were slow.

An even simpler periscope was merely a mirror, about three inches long and an inch and a half wide, which could be placed on a bayonet or a stick and set up over the trench so that it gave a view of the ground in front. A total of 100,000 of these was delivered before the end of July, 1918, and 50,000 additional ones before November.*

At the beginning of the war all textile equipment, such as cartridge belts, bandoleers to carry ammunition, haversacks, pack carriers, pistol holsters, canteen covers, and similar material, were supplied in woven material. Only two concerns in this country could manufacture articles of this quality. They

* Further facts about periscopes are included in the chapter entitled Sights and Fire-Control Apparatus.

were the Mills Woven Cartridge Belt Company, Worcester, Massachusetts, and the Russell Manufacturing Company, Middletown, Connecticut. Although these two concerns practically doubled their output and worked day and night to supply the material, the demand was too great, and belts and carriers were designed to be stitched and sewn instead of woven. Equipment made in this manner is inferior to the woven. The Mills Woven Cartridge Belt Company produced approximately 3,200,000 of the woven articles and the Russell Manufacturing Company 1,500,000. Large producers of the stitched and sewn material were the Plant Brothers Company, Boston, Massachusetts; R. H. Long Company, Framingham, Massachusetts; and L. C. Chase Company, Watertown, Massachusetts.

For the Browning automatic rifle and the Browning machine gun there were specially designed belts and bandoleers. The rifleman had his own special belt, his first and second assistants had their own individual belts, and the assistants also had two bandoleers each, one right and one left, which were carried across their shoulders. These were manufactured in quantities by the following manufacturers:

R. H. Long Company, Framingham, Massachusetts	175,000
Plant Brothers Company, Boston, Massachusetts	75,000
L. C. Chase Company, Watertown, Massachusetts	20,000

Many small articles of textile equipment were produced in immense quantities. Approximately four and a half million canteen covers were produced before November 1, 1918. Large contracts were placed with the following concerns: Perkins-Campbell Company, Cincinnati, Ohio; Brauer Brothers, St. Louis, Missouri; L. C. Chase Company, Watertown, Massachusetts; Miller-Hexter Company, Cleveland, Ohio; Powers Manufacturing Company, Waterloo, Iowa; R. H. Long Company, Framingham, Massachusetts; Bradford Company, St. Joseph, Michigan; Galvin Brothers, Cleveland, Ohio; and Progressive Knitting Works, Brooklyn, New York.

Approximately four and a half million haversacks were produced and delivered, also before November 1, 1918. Large manufacturers producing these were as follows: Canvas Products Company, St. Louis, Missouri; Rock Island Arsenal, Rock Island, Illinois; Plant Brothers Company, Boston, Massachusetts; Simmons Hardware Company, St. Louis, Missouri; R. H. Long Company, Framingham, Massachusetts; Liberty, Durgin (Inc.), Haverhill, Massachusetts; and Wiley, Bickford & Sweet, Hartford, Connecticut.

It is impossible here to enumerate the entire range of ordnance munitions produced, outside the development of guns and their ammunition; but the manufacture of such munitions, in orders that ordinarily amounted to millions of individual pieces, engaged the activities of a large number of manufacturers of the United States.

The Government ordered about 1,200,000 axes to be used in trench operations, of which 661,690 were delivered. Deliveries of bags of all sorts for horse feed, grain, rations, and supplies totaled about 2,250,000. The Government received 809,541 saddle blankets; about 3,750,000 carriers for entrenching shovels, axes, and picks; nearly 4,450,000 covers for the breech locks of rifles; over 1,000,000 currycombs; 76,230 lariats; 727,000 entrenching picks; nearly 4,750,000 first-aid pouches, and over 2,000,000 pouches for small articles; 234,689 cavalry saddles; 134,092 field artillery saddles; 15,287 mule saddles; 482,459 saddlebags; nearly 1,800,000 entrenching shovels; 2,843,092 spur straps; and 70,556 steel measuring tapes, each five feet long. These figures, selected at random from thousands of miscellaneous items, indicate something of the scale on which America went to war.

The old model 1910 American wire cutter, although efficient in times past, was not capable of cutting the specially constructed manganese wire which the Germans used. It was necessary for this country to develop a better cutter. A meeting of the plier manufacturers of the country was called, and the question was put before them. The spirit of coöperation of the American manufacturers was evident, for over 90 per

cent of the manufacturers attended the meeting. The model submitted by Kraeuter & Company, Newark, New Jersey, was adopted, and 5,000 were manufactured and sent to France. Although this was the best cutter developed hitherto, it was evident that it was not the ideal article, and the Engineering Division of Ordnance continued experimenting to make a more satisfactory one. In this connection a one-hand wire cutter was developed by the William Schollhorn Company, of New Haven, Connecticut. This cutter was an efficient and satisfactory article, and, although it was never adopted by the American Army during the war, it is worthy of mention. The American Expeditionary Forces eventually sent back drawings and samples of the French wire cutter, which was developed abroad and known as model 1918. This was a large two-hand cutter. Production was started. The article was found difficult to manufacture, but the manufacturers undertook it with a will, and production was well under way when the armistice was signed.

The mess equipment of the soldier included the following items: meat can, condiment can, canteen and cup, knife, fork, and spoon. These articles were practically the same as the Army had always used, with one exception—the meat can. Advice was received from the American Expeditionary Forces that the meat cans in which the soldiers' food was placed by the cooks of the various organizations were not large enough to hold the portions that the American doughboys needed when they were fighting at the front. Although production on the old model was well under way with various American manufacturers, a new model can was designed which was half an inch deeper. The American manufacturers immediately, with a great deal of trouble to themselves, changed their dies and tools and manufactured the new and larger can, of which thousands were turned out daily.

CHAPTER XVI

NAVY ORDNANCE

IT would be unfortunate if the reader gained from the preceding chapters an impression that the War Department was the sole producer of ordnance supplies during the war. The United States Navy had its ordnance problems, too; and some of the largest industrial operations in the United States during 1917 and 1918 were prosecuted in behalf of the Navy. The navy ordnance enterprise, to be sure, could not compare in size with that of the Army, and it required no such elaborate preliminary creation of special facilities; yet that it was a business of large extent is certified by the fact that the total navy commitments for ordnance of various sorts during the World War amounted to more than $800,000,000 in value.

As a general rule the naval ordnance projects reached much more advanced stages of development than did those of the War Department. Whether because of the superior efficiency of the Navy's single purchasing agency, as compared with the early disastrous army plan of purchasing through the various independent procurement bureaus, or because the Navy's ordnance industry was smaller than the Army's and therefore easier to manage, or because of a spirit of aggressiveness characteristic of the Navy, or because of all these factors, the navy ordnance officers had the satisfaction of seeing the major sorts of supplies which they labored to procure produced in heavy quantities and actually employed—employed effectively, moreover—in combat operations against the enemy. One of these supplies, based on an invention developed by the Navy's Bureau of Ordnance during the war, had perhaps as much to do with compelling the early capitulation of Germany as any other material thing that could be named.

The first great responsibility which fell upon the Navy's

Bureau of Ordnance was to arm the merchant ships sailing under the American flag. To Germany's proclamation of unrestricted submarine warfare, the reply of the United States was the order of the Secretary of the Navy of March 13, 1917, requiring the arming of all American merchant ships voyaging into the danger zones and designating crews of navy marksmen to man the guns on these ships. These gun crews were called Armed Guards, a designation that continued in use until the armistice. The exploits and adventures of the Armed Guards, placed as they finally were on more than 500 American cargo and passenger vessels, form one of the heroic chapters in the history of American participation in the World War. The arming of vessels was one of the important measures in the combination of offensive and defensive operations which effectively checked the successes of the enemy's submersibles.

The conditions of naval warfare in 1917 and 1918 laid the emphasis upon the production of guns of the smaller sizes. For years prior to the declaration of war the tendency had been all the other way: battleships were made larger and heavier, with main batteries of larger and larger guns. The 14-inch gun had become standard for the turrets of our capital ships, and the designers were forecasting the day when 15-inch and 16-inch rifles would be mounted in the main batteries of capital ships. The effect of the declaration of war was to suspend all construction in our ambitious capital-ship program in order that the shipbuilding facilities at the disposal of the Navy might concentrate upon the construction of destroyers, submarines, submarine chasers, patrol boats, mine sweepers, and all other small craft especially adapted for use in the submarine war. Even without further construction of capital ships the Grand Fleet of the Allies held the safe preponderance of floating power, and the enemy would not come out from his fleet bases and give battle on the surface. Therefore there was no need of any more battleships and cruisers than we already possessed. But at no time did America and the Allies have as many anti-submarine vessels as they could have used. The re-

sult was a feverish construction of such vessels in the navy yards of the United States, an effort which produced records of construction never equaled either by ourselves in the past or by any of the Allies contemporaneously.

A corollary of this policy in the Navy Department's Bureau of Ordnance was the partial withdrawal of attention from the production of guns of the larger calibers and increased attention to weapons adapted to use against the thin-skinned submarines—guns which small patrol craft could carry easily and guns the firing loads of which could be supported by the relatively frail construction of the decks of merchant ships. These two considerations produced a sharp limitation of the sizes of guns. The 6-inch gun, 50 calibers, was the maximum size used, but the 3-, 4-, and 5-inch guns were far commoner. The disadvantage in the 3-inch and 4-inch guns was the fact that the later German submarines carried 6-inch guns which could outrange them. One hundred and sixty-nine 6-inch guns were mounted on the decks of American transports and merchant vessels; guns of the 3-inch and 4-inch sizes numbered 652. In all, including destroyers, Eagle boats, sub-chasers, and other war craft used in the danger zones, as well as transports and merchant ships, the Navy armed 1,868 vessels during the war, using 2,501 cannon for the purpose, in addition to 2,850 machine guns and 1-, 3-, and 6-pounders. One 3-inch Davis non-recoil gun, the principal use of which was on aircraft, was mounted on a submarine patrol boat.

The business of procuring this great number of weapons was one of the chief tasks for the Bureau of Ordnance during the war. The enterprise was started well in advance of the actual declaration of war. In the two months between the time we recalled our ambassador from Berlin (February 3, 1917) and the time we declared war against Germany (April 6, 1917), the Bureau of Ordnance placed contracts for the construction of 2,500 guns of small caliber, of which 1,300 were of the 3-inch, 4-inch, and 6-inch sizes. This expedition in the Bureau of Ordnance resulted in a heavy production of guns in 1918, at the time when merchant vessels were coming under the

American flag in greatest number and when the shipyards had reached quantity production in their output of war craft for the submarine zone. Though the Bureau of Ordnance now and then had to turn some sharp corners, it always had the guns ready when the ships were ready for the guns.

In these ante-bellum weeks, too, the Bureau of Ordnance was busy in other directions. In advance of the declaration of war, it placed orders for the ammunition for the guns put in procurement, and also ordered such things as machine guns, rifles and pistols, mines, aircraft bombs, and submarine nets. It is noteworthy that among these early orders was a contract calling for the manufacture of 3,850 projectiles for 14-inch guns. Later on, the Navy, as was noted in Chapter V, provided railroad mounts for a number of the 14-inch battleship guns which it had in reserve, and sent several batteries of this *matériel* to France, where they gave effective service during the final drive which ended in Germany's defeat. The projectiles used by these batteries, 782 of them in all, were part of those ordered before the declaration of war. The advantages of an early start in the production of munitions of war were, then, clear. The Army, delaying for several months after the declaration of war the proper inauguration of the manufacturing end of its ammunition program, was unable to place in France any appreciable quantities of artillery ammunition in time for it to be fired against the enemy.

If the Navy had depended upon new production to supply the guns needed during the war, many of the vessels which were actually armed would have had to go without guns. Even under the most favorable circumstances it takes a long time to build a gun; and the Navy, like the Army, had to rely, in large part, for the supply of weapons on its war contracts, upon new gun plants, built and equipped after the war emergency began. The Navy went into the war with only 376 guns of suitable sizes in reserve. The demands upon the Bureau of Ordnance for guns of the 3-inch, 4-inch, 5-inch, and 6-inch sizes amounted in all to more than 2,700 such weapons. The total production of these sizes during the war amounted to

about 2,000 guns, but this production occurred almost entirely in the year 1918, and the heaviest part of it in the three months before the armistice. After exhausting its own reserve supply of guns in the arming of ships, the Bureau, in order to bridge the gap until the new production could start, went to the fleet and stripped the battleships and cruisers of their secondary batteries, obtaining from this source a total of 490 guns.

Another consequence of the conditions of warfare at sea was that this withdrawal of light guns could be carried out without weakening the fleet. On the contrary, it strengthened it. The secondary batteries of which these guns were part, nearly always located between decks in the battleships and cruisers, were fired through ports in the vessels' sides. Such cruisers and other large war vessels as were to be used in the danger zones had only the submarine to fear. Immediately after the explosion of a torpedo the stricken ship almost invariably listed heavily to one side or the other. This list was of only brief duration, and after it the vessel would right itself and might then be salvaged if its water-tight bulkheads held. If, however, there were open ports in the vessel's sides, a fatal amount of water might be taken in through these openings in the first list after the torpedo struck. Consequently the practice was to prepare capital war vessels for war-zone service by removing the between-decks guns and sealing the ports. This practice made available a considerable number of guns which could be used for arming merchant vessels.

The Bureau of Ordnance first went to the fleet for guns on March 27, more than a week before the declaration of war. At that time it took thirty-eight 3-inch, 50-caliber guns from the big ships. On April 26 the Bureau received authority to take 184 more, ranging in size from 3-inch, 50-caliber guns to 6-inch, 50-caliber guns. Two days later the Bureau obtained 180 additional 3-inch 50's. The cruiser *Memphis* stranded on the coast of San Domingo, and her light guns were salvaged and used for arming merchant ships. The *Milwaukee* went on the shore in California, and all of her 3-inch and 6-inch guns became available for merchant ships. During the summer and

early fall of 1917 the Naval Gun Factory in Washington began delivering a few new guns suitable for this purpose—these on orders placed with the factory considerably in advance of the declaration of war. On October 1, 1917, the arming of merchant ships and anti-submarine craft had exhausted the guns at the disposal of the Bureau of Ordnance. The ships were coming in to be armed in ever-increasing numbers. On the 4th day of that month the Bureau again went to the fleet and took from it fifty-six more guns, although now the fleet could not well spare them. Again on December 7 the Bureau once more raided the battleships and cruisers and took seventy guns, mostly of the 5-inch and 6-inch sizes. But this requisition absolutely exhausted that source. The fleet could give up no more without impairing its own fighting efficiency.

Fortunately, the first of the Navy's war contracts for guns were then about to bring forth results. Because of the severe weather conditions in the early weeks of 1918 and the simultaneous congestion of shipping (which was not to be relieved until the Shipping Control Committee took hold in February), only a few merchant ships presented themselves in that interval to be armed. In January the Linderman Steel & Machinery Company, of Muskegon, Michigan, delivered the first naval gun mount produced in the United States under a war contract. It was a mount for a 4-inch gun. The first gun delivered under a war contract came from the new gun plant of the Root & Van Dervoort Engineering Company of East Moline, Illinois, on April 3, 1918—a 4-inch gun. Other war contracts were then at the point of reaching production. As spring advanced the Bureau began receiving an ever-increasing supply of new guns and mounts; but at this time also the Shipping Board was most active in building up the merchant marine by chartering and seizing vessels and also by new construction. The result was that, though the Bureau stimulated and speeded up production by every method at its command, at the navy yards on the Atlantic coast there never were at any time more than a dozen guns on hand without places to put them. Not until the fall of 1918 did ordnance construction gain on the demand for

guns, and then most of the principal contractors had reached the stage of quantity production. On the day of the armistice the Bureau found itself with a reserve of fifty guns, although tonnage was then coming under the flag at a rate never equaled before or afterwards.

The Navy's Bureau of Construction and Repair installed the guns on the merchant ships as well as on the new war craft which needed weapons of these sizes. The installation of a gun on a merchant vessel was no simple job. The deck had to be strongly reinforced and all foundations made secure enough to stand the shocks of firing. The arming meant more to a ship than a gun platform and a strengthened deck. It meant ammunition compartments in the hold, ammunition chests on deck, ammunition-passing scuttles, and speaking tubes and other communication devices. All of this work of installation was done by gangs from the Atlantic coast navy yards, and principally from the New York Navy Yard, although a few ships were armed at Philadelphia and Norfolk. The guns were installed while the vessels were loading or unloading.

The merchant marine grew to a tonnage which far surpassed the Navy's expectations, and its size necessitated a change in the practice of arming merchant vessels. At first the Navy placed from three to six guns on a single ship, but such heavy armament was soon found to be impracticable. It was impossible to supply either guns or gun crews in such numbers. Moreover, it was hard to find good locations for so many guns on a single ship, and a multiplicity of guns on deck interfered unduly with cargo handling. For these reasons the Navy adopted the standard practice of two guns to a ship—a 3-inch, 50-caliber gun forward, and a heavier gun at the stern. This was found to be an effective armament.

Incidentally, during this period of war construction the Navy manufactured an entirely new gun especially adapted to use against submarines and aircraft. This was a 3-inch gun only 23 calibers in length, or five feet, nine inches. The gun was designed especially for a war vessel new to our Navy, the 110-foot submarine chaser. This useful fighting boat, though

stanch and seaworthy, was not large enough to mount a heavy gun of any of the usual calibers. Yet the chaser needed a gun that would throw a shell of sufficient size to be effective against a submarine. The 3-inch, 23-caliber gun was the answer to this problem. It threw a 3-inch shell, but thanks to its short barrel, which reduced its power (though not below the point of destructiveness), and to its long recoil, it did not put overheavy firing loads on the decks of the chasers. This gun was designed by the Poole Engineering & Machine Company of Baltimore, which delivered the first gun within seven months after the date of its contract. This concern and others produced 532 3-inch, 23-caliber sub-chaser guns before the armistice.

The famous Davis non-recoil gun, although designed for use primarily on airplanes, was put in production by the Bureau of Ordnance for use on small patrol vessels. These Davis boat guns threw a 3-inch shell with sufficient force to penetrate the armor plating of a submarine. The Bureau designed and started the production of 8-inch howitzers, ordering 100 of them. This howitzer was a sort of glorified trench mortar, designed to throw a big shell holding seventy pounds of T. N. T. about a mile and a half. These, with the 3-inch, 23-caliber gun and the now familiar Y-gun, were the principal ballistic novelties produced by the Navy during the war.

Like the Army, the Navy was forced to procure most of its guns of large caliber on war contracts placed with companies which had to create new facilities for manufacture and to train their staffs in the difficult art of gunmaking. Four concerns—the Tioga Steel & Iron Company, the Inland Ordnance Company (a subsidiary of the McMyler Interstate Corporation), the Alloy Steel Forging Company, and the Erie Forge & Steel Company—took the navy contracts for gun forgings, all of them building new plants for the work except the Inland Ordnance Company, which built an extension to its existing plant. Besides the Root & Van Dervoort Engineering Company and the Poole Engineering & Machine Company, the concerns which contracted to make navy guns from the forgings were:

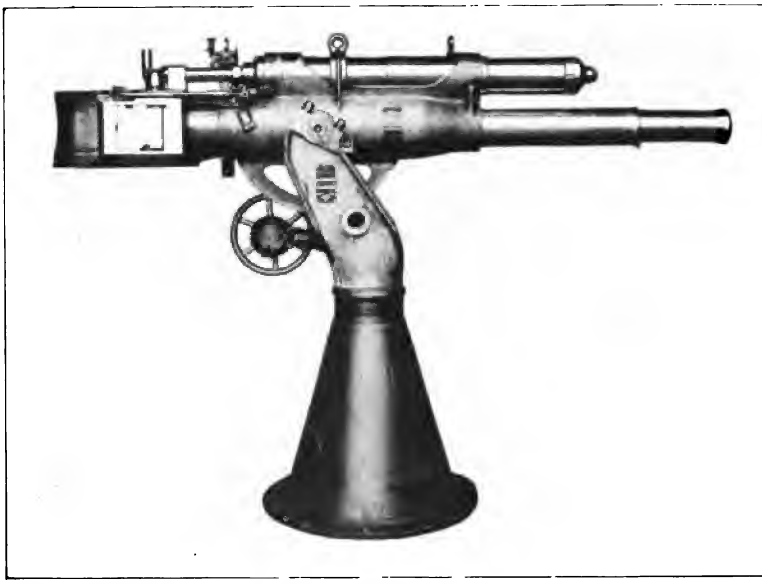


Photo from Bureau of Ordnance, U. S. N.

THE 3-INCH 23-CALIBER BOAT GUN

Photo from Mead-Morrison Manufacturing Company

WAR ORDNANCE SHOP CROWDED WITH NAVY WORK

Photo from Bureau of Ordnance, U. S. N.

NAVAL 8-INCH HOWITZER

Photo from Bureau of Ordnance, U. S. N.

DEPTH-CHARGE LAUNCHING GEAR

the American Radiator Company, the General Ordnance Company, the Four Lakes Ordnance Company (affiliated with the Steinle Turret Machine Company of Madison, Wisconsin), the Defiance Machine Works, the Driggs Ordnance Company, the Savage Arms Corporation, and the Liberty Ordnance Company, formerly known as the Bridgeport Projectile Company. All but four of these concerns built new plants for the navy contracts. Thus, in the work of supplying to the Navy guns only, without mounts, eight great new ordnance factories were built in the United States, and five other large factory additions constructed and equipped. Most of these concerns reached quantity production before the armistice. Two in which the work was backward were commandeered by the Government and turned over for operation by more experienced and efficient concerns.

Besides the guns the Navy had to have mounts for them. To find concerns capable of manufacturing such *matériel* with the least disturbance to existing *personnel* and shop equipment, the Navy turned to the producers of such heavy metallic structures as printing presses, coal-handling machinery, woodworking machinery, and motor cars. The successful producers of naval gun mounts were the Linderman Steel & Machinery Company of Muskegon, Michigan; the Mead-Morrison Manufacturing Company, Boston; the Ohmer Fare Register Company of Dayton; the Miehle Printing Press & Manufacturing Company, Chicago; the Goss Printing Press Company, Chicago; R. Hoe & Company, New York; the Russel Motor Car Company, Buffalo; the Poole Engineering & Machine Company; and the American Steel Products Company, Brantford (Ontario) plant.

Because of the inability of the American foundries to cast steel in a way that could pass the inspection of the Navy Department, the mount makers experienced considerable difficulty in obtaining steel castings. The Superior Steel Castings Company, of Benton Harbor, Michigan, was the first concern which produced satisfactory mount castings, and for several months the Bureau of Ordnance had to allocate the output

of this plant among the various producers of mounts. Sights were another stumblingblock. The Naval Gun Factory at Washington stepped in and rebuilt sights which could not pass the acceptance tests, thus permitting the early use of many new mounts which were ready for service except for sights. One manufacturing feat should be noted—that of the Poole Engineering & Machine Company. This company was concentrating upon the production of the 3-inch, 23-caliber gun—both tube and mount—which was its own design. Finding it impossible to secure satisfactory steel castings for the mounts, the Poole Company experimented with bronze and produced a satisfactory mount made of bronze, a metal which the foundrymen were able to cast. The result was that the Bureau authorized the substitution, and in a short time the company began turning out the mounts. This quick turn enabled half a hundred new submarine chasers, sorely needed in the European war zone, but held up for suitable guns, to proceed across the ocean almost immediately.

The mount makers began delivering mounts early in 1918 and, by the date of the armistice, had completed 3,658 of them.

Through all this work the Naval Gun Factory, which had always been the Navy's main reliance for its broadside guns, was of invaluable assistance. The Factory actually built more than 300 guns and mounts of various sizes during the war, and it examined and prepared for service every gun and mount produced by the private manufacturers. In addition it sent its experts out to the various new ordnance plants and helped them to solve their manufacturing difficulties.

The Navy's use of small arms is not great, and therefore its production of such ordnance during the war was not large. For machine guns to be fired from fixed mounts on the decks of destroyers or submarine chasers the Bureau adopted the Colt and Marlin guns, both heavy, air-cooled weapons, and produced 1,500 of the former and 1,605 of the latter during the war. The Navy adopted the Lewis gun as its light machine gun and procured 4,204 of them during the war. From the

War Department the Navy bought 2,000 Browning machine guns and 442 Browning rifles for the Marine Corps. The Navy also procured rifles, pistols, and other landing-force equipment from the Army—the totals being approximately 33,000 rifles, 24,000 pistols and revolvers, and 20,000 Very signal pistols.

A small-arms novelty was the line-throwing rifle, a life-saving appliance developed by the Bureau of Ordnance in conjunction with the firm of William Reid & Sons. This was a caliber-.45 rifle which would throw a metal projectile 200 feet carrying a light cotton line along with it. The company built 500 of these.

The ammunition problem of the Navy was to supply powder and shell to the relatively small guns—from 1-pounders up to 6-inch guns—since, except for the 14-inch railroad guns sent to France, the bigger guns of the Navy were not fired against the enemy. The Army's powder needs were regarded as paramount to those of the Navy, and therefore the Navy, after the declaration of war, conceded the existing private manufacturing facilities to the Army and proceeded to expand its own powder factory at Indian Head, Maryland, not far from Washington. This work continued throughout the war, and at the armistice the Naval Powder Factory alone was producing at a rate that was beyond the war consumption. The Navy, however, placed contracts early in the war with the DuPont Company and the Hercules Powder Company for a total of 43,000,000 pounds of powder, most of which was delivered before the armistice.

Nearly all the guns on merchant vessels being of the sizes which use fixed ammunition, the Bureau of Ordnance had to procure a large number of brass cartridge cases. These were produced in sufficient quantities by large brass manufacturing concerns, among which were the Scoville Company of Waterbury, Connecticut, the Gorham Manufacturing Company of Providence, and the Toledo Brass Casting Company of Toledo.

The Navy's shell program, too, deferred to the Army's, the Navy on several occasions agreeing to cancel entire contracts

for projectiles in order that the Army Ordnance Department might have the use of badly needed facilities. Through the mediation of the War Industries Board and of the American Iron and Steel Institute, there was always close coöperation and harmony between the two ordnance bureaus in their shell projects. In the course of its shell program the Navy developed and produced a flat-nosed projectile that would not ricochet upon striking the water, but would dive and continue in an under-water trajectory.

The Navy's smokeless powder program, though not to be compared with the Army's in size, nevertheless had to have its raw materials, of which there were not enough to satisfy the Army alone. Consequently the Navy Bureau of Ordnance was forced to develop its own sources of supply. This was particularly true with reference to its supply of nitrates. In the summer of 1918 the Bureau began the construction of a nine-million-dollar nitrogen-fixation plant at Indian Head, near the Naval Powder Factory. This plant was designed to produce 115,000 pounds of nitric acid daily, a quantity sufficient to meet the needs of the powder plant when the latter was turning out its capacity production of 100,000 pounds of smokeless powder a day. The Naval Nitrates Plant adopted the de Jahn fixation process, a modification of the original German Haber process, by which ammonia is produced by the direct synthesis of nitrogen and hydrogen. The ammonia is then oxidized by the Oswald method to produce nitric acid. The J. G. White Engineering Company of New York, under the direction of the General Chemical Company, held the contract to construct this plant; but at the armistice the construction was stopped and the contracts were terminated.

High explosives were a war commodity much more important to the Navy than smokeless powder. The latter was used only in propelling projectiles from guns, and the naval vessels did not get many chances to fire their guns at enemy craft or shore fortifications. High explosives, however, were the bursting charges, not only of shell, but also of the weapons with which the Navy met the enemy on his own plane of operations

at sea—namely, under the surface. To load its mines, depth charges, bombs, and torpedoes, and also its shell, the Navy needed 50,000,000 pounds of trinitrotoluol *per annum*, or a good one-fourth of the total American and Canadian annual production of that explosive.

But the general explosives program of the War Department alone called for more than the total domestic production of T. N. T. Therefore, while necessarily submitting to a curtailment and rationing of its T. N. T. needs, the Navy set about finding a substitute. The limiting factor in the production of trinitrotoluol was the toluol itself—witness the desperate efforts of the Army to secure it by stripping illuminating gas, building recovery plants at oil refineries, and encouraging the erection of by-product coke ovens. Next to toluol in the so-called benzine scale is the basic material xylol. Nitrated xylol is an explosive practically as effective as nitrated toluol (T. N. T.). The manufacture of T. N. X., as trinitroxylol is called, demanded both nitric and sulphuric acid, as does that of T. N. T., but not toluol. Therefore the Navy adopted T. N. X. as a substitute explosive, and contracted with the DuPont Company for the erection of a huge T. N. X. plant, to cost nearly $4,000,000 and to produce 30,000,000 pounds of T. N. X. annually. The one disadvantage of T. N. X. as a war explosive was that it did not mold readily into mines and other containers; but, mixed with a small amount of T. N. T., it gained a satisfactory plasticity.

The erection of the Navy's T. N. X. plant at Barksdale, Wisconsin, was one of the great industrial achievements of the war. The contractors began work in March, 1918, before the contracts were even signed. The plant was turning out satisfactory T. N. X. in October, 1918, and on the day of the armistice was within three weeks of reaching the stage of capacity production. T. N. X. was not an unknown substance, but it had never before been produced on a large commercial scale. The achievement of the DuPonts in developing this great manufacture in eight months includes the development of practicable factory processes by laboratory experimentation.

Once it had embarked on this great project, the Navy had next to turn to the development of the supplies of xylol, only a little of which was being produced. Being a coal-tar product, xylol comes from the same sources that supply toluol—coke ovens, oil refineries, and the like. The Navy Bureau of Ordnance entered into contracts with a hundred or more source plants to supply crude xylol to the Barrett Company, which contracted with the Navy to refine the product for use in the T. N. X. plant.

It was the Bureau of Ordnance of the Navy which discovered after the armistice the enormous extent to which Germany had developed the fixation of atmospheric nitrogen. The Bureau sent Lieutenant R. E. McConnell, U. S. N. R. F., to Germany when the fighting ceased, primarily to study the fixation processes in use there with the view of perfecting our own methods. At Ludwigshafen Lieutenant McConnell discovered a plant with an annual capacity of 100,000 tons of nitric acid, ten times the capacity of the first army fixation plant built at Sheffield, Alabama. The Germans had started the erection of this plant in 1907, but it was not until the beginning of 1914 that they attained success in the fixation process—a fact which historians, in fixing responsibility for the World War, are likely to regard as significant. From the early months of 1915 until the defeat of the German Army this plant had worked night and day, with the exception of one 12-hour interval when the plant was repairing its water system, temporarily out of commission after the explosion of a bomb well placed by an Allied aviator.

But this plant afforded not half the total German domestic supply of nitrogen. On the outskirts of Berlin another huge fixation plant had been erected, a plant half as large again as the one at Ludwigshafen. These two plants gave Germany an output of nitrogen greater than the combined importations of nitrates from Chile by all of the Allies during any one war year. Germany started the war with a reserve of more than 500,000 tons of Chilean nitrates, a quantity augmented by 200,000 tons taken as booty in the fall of Antwerp.

Although the arming of vessels was important,—without it the convoy system might not have been the success that it was,—it was nevertheless in the production of under-water weapons to harry and destroy the submarine in its own element that the Bureau of Ordnance scored its most signal inventive and industrial victories. One of these weapons was the depth charge. Before Germany showed the world the elusiveness of the submarine, the consensus of naval opinion was that the gun and the torpedo would provide a sufficient defense against submarines. In those days submarines were slow in emerging and submerging, and it was thought that gun pointers on surface craft could make things sufficiently interesting for submarines to hold them in check. The German submarine commanders, however, became exceedingly expert in their work, and the under-water boats themselves were greatly improved. The submarine, with its low freeboard, could see the approach of a surface vessel long before the latter could make out the submarine. The submerging time became greatly reduced. Therefore it became evident that gunfire was of little avail against submarines, and that if the Allies were ever to make headway in an offensive campaign against the U-boats they must invent weapons that would go down and get the enemy where he chose to live at sea.

The depth charge, a sinking bomb that could be made to explode at any desired depth, was one of the responses to this need. For its effectiveness the bomb utilized the principle of the incompressibility of water. The so-called "water hammer" is familiar to anyone who has ever turned off a water tap suddenly and heard the noise of the shock produced by the water hammer within the pipe. The water hammer resulting from a heavy explosion under the surface of the ocean could be relied upon to damage any submarine near the explosion and at close range even to sink it.

A contact charge was neither desirable nor necessary—undesirable because of the improbability of dropping a charge so accurately that in sinking it would hit a submarine, unnecessary because of the water hammer. Therefore the inven-

tors set to work to develop firing mechanisms that could be set for desired depths and would touch off the explosives when the charges sank to those depths. These firing devices were among the Allies' best-guarded secrets, and we had no knowledge of their mechanical principles until we too became a belligerent. Then the Allies—the British had done the most advanced work in this direction—gave us their secrets. But it was not until after the United States entered the war that the depth charge received extensive development and use.

Yet the Bureau of Ordnance was not caught entirely unprepared with depth charges. Its experts had been studying the problem and had developed a depth charge of their own. In February, before the declaration of war, the Bureau placed contracts for the manufacture of 10,000 of these American depth charges, and the contractors so pressed their work that they were able to deliver charges immediately after America became a belligerent.

For the depth charge of this early type, however, not much can be said. It was fired by the float-and-line principle. When a charge of this type was thrown overboard, a small buoy detached itself from the charge and floated on the surface. To this buoy was attached a line, which was paid out by the charge as it sank. At any predetermined depth the depth charge ceased to pay out line, and the jerk then given to the charge by the floating buoy fired the charge. This firing device, though ingenious, was erratic, and was not to be compared in efficiency with the hydrostatic pressure firing gears developed by the British and later by ourselves. The chief defect of the early American depth charge, however, was its small explosive charge. It contained fifty pounds of high explosives, whereas the contemporaneous British depth charges, which the British Government made available for our inspection immediately after April 6, 1917, held 300 pounds. The water hammer which we had proposed to use against the enemy submarines was hardly more than a tack hammer, whereas the British were using a sledge.

The inspection of the British charges at once changed the

ideas of the Bureau of Ordnance as to this sort of war *matériel.* The operating side of the Navy at once urged the adoption of the British charge as it was. Our own designers, however, had meanwhile been busy working on firing mechanisms and had developed at the Newport Torpedo Station a hydrostatic firing gear that gave a range of depth setting greater than the British gear. Consequently the Bureau adopted the British cylinder and the British standard weight of 300 pounds of high explosive, but fitted to this the American firing gear and called this assemblage of parts the American Mark II depth charge. Some 35,000 of these charges were produced. Our destroyer crews considered the American charge to be fully as effective as the British and even more reliable, as the British themselves also testified.

The principle that pressures under water vary with the depth made the hydrostatic pressure firing gear possible. The later American gear could be set to explode the charge at any one of several depths from 50 feet to 200 feet. The British firing gear protruded beyond the cylinder end, whereas ours was installed protectively inside the case. The American charge was equipped with a safety device that made it impossible for the charge to explode until it was at least fifteen feet under water. A depth charge was simply a metal cylinder eighteen inches in diameter and twenty-eight inches long, the cylinder containing the explosive and the firing mechanism. Depth charges were ungainly missiles in appearance: the sailor men descriptively called them ash cans.

Thousands of American depth charges were manufactured, but, as the use of them developed with the development of anti-submarine tactics, the supply was never so great as the demand. The Bureau of Ordnance built 1,000 depth charges holding 600 pounds of T. N. T. instead of the commoner 300 pounds. Another late development increased the depth setting of the firing device to 300 feet.

The first depth charges were carried singly on slings which were dropped over the stern of a destroyer at the will of an officer holding a control lever on the bridge. The increased

use of depth charges and the setting up of so-called barrages of depth bombs around the suspected positions of hostile submarines made necessary the use of more rapidly working launching gear, and apparatus of two sorts was adopted and used in combination on the destroyers.

The first sort of apparatus was known as multiple launching gear. This gear consisted of a pair of parallel tracks, each holding a number of depth charges ready for dropping over the stern. A pull of a lever on the bridge sent one of the charges overboard. The early gear of this sort held sixteen charges, eight on a track. A later development increased the capacity of the gear to twenty-six charges in all. Another sort, holding ten charges, was designed for small boats. The Bureau of Ordnance built several hundred sets of these gears.

A more picturesque launching apparatus was the Y-gun. This was an American development of the British Thornycroft depth-charge thrower, a single-barreled gun on the end of which rested a depth charge lashed to an arbor, or stem, which fitted within the gun barrel. A charge of propelling powder, when touched off, threw out the depth charge to a considerable distance from the destroyer's rail. An officer of the American Bureau of Ordnance adapted the non-recoil principle of the Davis gun to a double depth-charge thrower of the Thornycroft type. In the Davis gun the barrel is open at both ends, and the recoil is nullified by the reaction of the propelling explosion against a weight, equal to the weight of the shell, which is expelled from the rear of the barrel as the gun is fired. The American officer, Lieutenant Commander A. J. Stone, U. S. N. R. F., put two Thornycroft guns together at an angle of forty-five degrees. The recoil forces, operating against each other at this angle, removed all but a small part of the firing load from the deck of the vessel carrying the gun. The Y-gun, of course, could not be fired one barrel at a time; it always threw two charges simultaneously. These were thrown out at distances up to eighty yards, the distance depending upon the size of the propelling charge.

The Y-gun was a simple manufacturing proposition. Start-

ing work on November 24, 1917, the General Ordnance Company, Groton, Connecticut, produced the first finished guns on December 10. The Navy put 947 Y-guns in service before the armistice.

Perhaps the most distinguished service rendered by the Bureau of Ordnance of the Navy Department during the war was the part it played in setting up the Northern Barrage, that famous barricade of T. N. T. which virtually closed to enemy submarines the wide entrance to the North Sea between the northern tip of Scotland and the Norwegian coast. The Bureau inaugurated the plan for this international British-American enterprise, developed the special-type mine which made the barrage possible, and actually manufactured most of the mines which went into it. The Northern Barrage was one of the important factors contributing to the defeat of Germany. One captured German submarine commander testified that the mines of the type used in the barrage were more dreaded by the Germans than any other anti-submarine measure. After the construction of the barrage the Government of Norway was forced to announce its intention to mine the Norwegian territorial waters because of the flagrant use of these forbidden waters by the German submarines—another indication of the effectiveness of the barrage. There is no question that the barrage greatly restricted the free use of Germany's most potent weapon; and since Germany had staked everything on the success of her submarine warfare, and had even courted the belligerency of the United States in order to employ it, it follows that, when the measures of the Allies not only checked the submarine, but even began to reduce its destructiveness rapidly toward the vanishing point, the German cause was as good as lost.

The notion of blockading the German submarines in their home bases had fascinated the Navy Bureau of Ordnance in Washington for some months before America entered the war. It was obvious that, if this could be done, it would be a complete protection to any American line of communication between this country and France. It was impossible to close the

actual German harbors, because the enemy maintained full control of his own territorial waters. The more difficult, but the next best, thing was to close the exits from the North Sea—the narrow strait between Dover and Calais and the 230-mile stretch of deep, rough, stormy, and foggy sea between Scotland and Norway. The Bureau adopted this plan as an ideal toward which it should work, if not as an actual policy. When we declared war against Germany our people discovered that the British had contemplated such a scheme more than once, but had always abandoned it as a visionary and impracticable undertaking.

Three methods of erecting an anti-submarine wall were contemplated: (1) with nets and entanglements; (2) with nets in combination with mines; and (3) with mines alone. With *matériel* of types then known to the Allies, not one of the three possible methods was feasible. Nets?—there were several objections to them, but one was sufficient: they could not be planted and maintained in water as deep as that between Norway and Scotland. Nets and mines in combination?—the same objection, at least. Mines alone? . . . .

The mine of the most improved type in the early spring of 1917 had the limitation that it would explode only upon contact with the hull of a vessel. It carried enough explosive to wreck a hull within one hundred feet of it, but it would not go off unless the hull actually struck it. The combined inventive powers of the Allies had been unable to invent a mine any more efficient than this. The submarine could run on the surface or at a depth as great as 240 feet or at any depth between these extremes. Therefore, to build an effective barrier of contact mines between Norway and Scotland meant the erection of a wall at least 200 feet high and 230 miles long, sowing mines in this wall so thickly that no submarine could go through without hitting one of them, and anchoring the whole wall in water in places as much as 1,100 feet deep. The combined manufacturing facilities of the anti-German world could not produce so many mines within a

reasonable time and at the same time turn out the other munitions which the armies and navies had to have.

Moreover, a main objection to all barriers of this sort was that they had to be heavily patrolled to prevent the enemy from sweeping and clearing passages. The German submarine commanders boasted that they were wont to use the hemispheres of contact mines for punch bowls, meaning that it was easy to clear them away. The patrol line across the northern entrance to the North Sea was so long as to be difficult of maintenance. If too thin, it could be broken up by enemy surface raids. If maintained with heavy vessels, the latter would be exposed to attack by hostile submarines and the losses would be heavy. If a mine could be developed that would largely protect itself, a mine which the enemy could remove only at great peril, then the situation might be different.

Reluctantly the Bureau of Ordnance accepted these conclusions of the British, reached by them only after long and bitter experience with the submarine. But the Bureau did not abandon its project. It set forth resolutely to develop a mine that would make the barrage scheme practicable.

A few days after the American declaration of war, one Ralph C. Browne, an electrician of Salem, Massachusetts, alighted from a train at Washington and enquired the way to the Navy Department. Had the importance of Mr. Browne to the Allied cause then been recognized and had it been discreet to stage a demonstration merited by the significance of this visit, instead of riding down Pennsylvania Avenue obscurely and humbly in a street car Mr. Browne would have been escorted by the Marine Band and a regiment of cavalry; for in his pocket he bore the plans for an invention that made the Northern Barrage possible. The inventor himself did not then realize the importance of what he possessed. He brought to Washington the plans for a submerged gun, which he called a "monkey on a stick." This gun he proposed to set under water in areas haunted by submarines, like the trap guns of a meat and fur hunter. The gun itself the navy experts rejected as impracticable. The amazing attribute of this gun,

however, the revolutionary thing, was that *it would discharge automatically whenever anything came within a considerable radius of it.*

Here was the firing mechanism which the naval inventors of the world had for years been seeking in vain. The Navy kept Mr. Browne right in Washington and attached him to the Mine Section of the Bureau of Ordnance. By June the Bureau had developed a successful mine embodying this firing device (which is still held as a national secret)—a mine which would do the work of three mines of the contact type; a mine most definitely not in the punch-bowl class, but one which it was exceedingly hazardous even to approach, as nearly a score of sunken and damaged vessels in our own mine-sweeping fleet after the armistice, and numerous dead and injured sailors on those vessels, gave tragic testimony. The new mine, known as the Mark VI, brought the northern barrage project well within the bounds of manufacturing and operational practicability.

The Secretary of the Navy and the Chief of Naval Operations approved the barrage plan in August. In September the Admiralty prepared the plans for the division of the work of mine planting. The British Admiralty finally approved the project in October. On October 29 President Wilson approved the project in the presence of the Cabinet. Meanwhile the Bureau of Ordnance had showed its courage by proceeding on October 3, nearly a month before the project was officially adopted, to let contracts for the manufacture of 100,000 such mines. Thus the mines were ready when the mine-laying fleet was ready to operate in the spring of 1918.

The Mark VI mine consisted of two principal parts—the mine sphere and the anchor. The mine sphere was simply two hemispheres of steel welded together at the equator. The resultant sphere contained the explosive (300 pounds of T. N. T.), the sensitive firing mechanism, and the safety devices. The latter were obviously necessary for the well-being of the mine planters. The detonator was never in contact with the main explosive charge until the mine had sunk thirty feet, when it was inserted in its proper place by a hydrostatic

Photo from Bureau of Ordnance, U. S. N.

MARK VI MINE RESTING ON ANCHOR

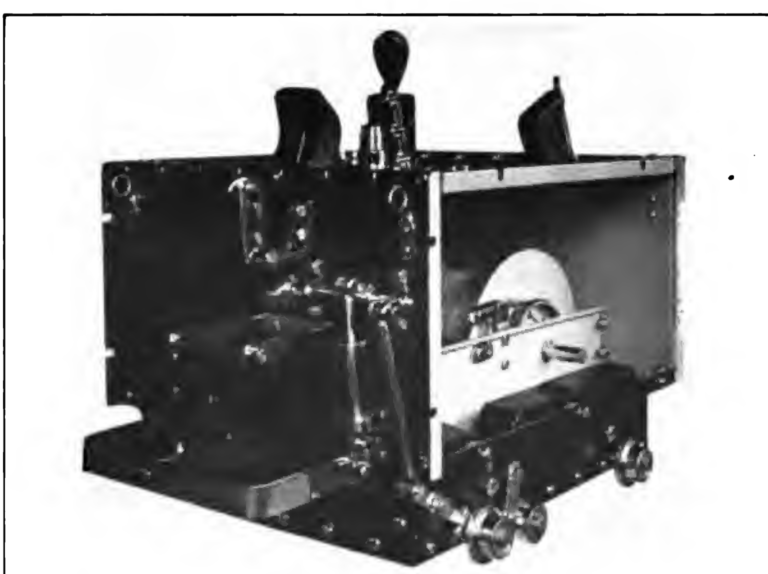


Photo from Bureau of Ordnance, U. S. N.

AMERICAN MINE ANCHOR OPEN TO SHOW DRUM AND CABLE

Photo from Bureau of Ordnance, U. S. N.

EXPLOSION OF DEPTH CHARGE

Photo from Bureau of Ordnance, U. S. N.

AMERICAN MINE SQUADRON PLANTING NORTHERN BARRAGE

device. By that time the hull of the mine planter would be well out of the sensitive area set up by the firing mechanism. Experiment showed that, if a mine detonator not in contact with the main explosive charge went off, the T. N. T. would not be fired. A further safety device, also operated hydrostatically, rendered the firing mechanism itself inoperative until the mine was thirty feet under the surface. Thus, both safety devices had to fail before there could be a premature explosion. Eighty-five thousand such mines were shipped loaded to Scotland; over 56,000 of them were actually planted; and there was not one accident.

The mine anchor was the British Mark VIII sinker, somewhat modified. This was simply a steel box two and a half feet square and two feet high, weighing with its contents about 816 pounds. It contained the mooring cable on a revolving drum and an ingenious device for drawing down the mine to any predetermined depth under the surface and mooring it there. This depth device consisted chiefly of a plummet containing an unreeling cord which could be set for any depth to which it was desired to sink the mine.

The action of mine and anchor after leaving the launching rails of the mine planter is about as follows: Before launching, the mine is attached to the anchor, both together weighing 1,400 pounds. They strike the water sideways, but the buoyancy of the mine immediately rights the anchor. The weight of the anchor being sufficient to overcome the buoyancy of the mine, both begin to sink together, slowly, until the plummet is released. The plummet is attached to the outside of the anchor box. Within the plummet is a cord which pays out easily and allows the plummet to sink swiftly. We will say that the mine planter is working in water 1,000 feet deep and desires to anchor this mine sixty feet below the surface. The plummet cord is set to pay out sixty feet and then stop. When the plummet reaches this sixty-foot limit below the slowly sinking anchor, it jerks on its cord, and the jerk releases the mine from the anchor. The main cable drum within the anchor is now revolving freely, and the mine bobs to the surface, as

the mooring cable pays out from the drum, and floats there. Relieved of the retarding buoyancy of the mine sphere, the anchor now sinks swiftly, paying out mooring cable as it sinks and piloted into the depths by a plummet down at the end of a cord sixty feet long. When the anchor reaches the depth of 940 feet, the plummet strikes the bottom. When the plummet's weight is taken off the anchor, the mooring cable drum is automatically locked. The anchor sinks slowly now, for it is pulling the mine down with it once more; and when it has sunk sixty feet in this way, the mine anchor itself touches the bottom, thus mooring the mine sixty feet below the surface.

This was the complicated mechanism which the Navy proposed to manufacture to the number of 100,000, laying the development plans with the view of gaining a production of 1,000 completed mines and anchors a day. It is believed that this was the only great single munitions project carried out in the United States about which the enemy received no inkling of information from his secret agents in the United States. Only a few persons in the United States knew about the mine, and they were trusted officers of the United States Navy. It was important that the German should not learn of this development in mining in advance of the actual use of the mines, or else he might be able to perfect a defense while the manufacture of the mines was in progress. Secrecy as well as manufacturing speed was gained by separating the mechanism into its component parts and allotting contracts for the manufacture of parts only. More than 500 contractors and subcontractors built parts for the mines, and not one of them knew the use of the thing which he was making. The Bureau of Ordnance even allowed the assembly plants to assemble no complete mines, but only unrelated groups of parts. The assembled groups of parts were shipped to the American mine bases at Invergordon and Inverness on the shore of Moray Firth on the eastern coast of Scotland, there to be assembled into complete units by navy *personnel*.

The mine spheres, however, were loaded with T. N. T. in this country, and for this purpose the Navy erected and

operated a mine-loading plant of twenty-two buildings on a swampy site at St. Juliens Creek near Norfolk, Virginia. This plant was built during the winter of 1917-1918 at a cost of $400,000, was ready to operate in March, 1918, and reached a loading rate of approximately 1,500 mines daily. The DuPont Company loaded some of the mines at its plant at Barksdale, Wisconsin. The Navy took over one of the largest terminal piers in the Hampton Roads district, that of the Southern Railway Company at Pinner Point, and used it exclusively in the export of mines for the Northern Barrage. Twenty-three cargo vessels became the transatlantic mine carriers. These were all small ships, built on the Great Lakes, but admirably adapted for the work. It was not desirable to ship the *matériel* on large vessels, for the loss of such a ship loaded with mine parts might seriously have embarrassed the barrage project. The *Lake Moor*, torpedoed on April 11, 1918, was the only one of the mine carriers lost.

It is not within the province of this account to go into any detailed description of the work of laying the Northern Barrage. It is sufficient to say that a fleet of mine planters—mostly fairly fast coastwise passenger steamers converted at various shipyards to this purpose—was assembled and placed under the command of Rear Admiral Joseph Strauss, who arrived with them at the Scottish bases on May 26. The first mines were planted on June 8, when the American planters laid a line of them forty-seven miles long. The two bases became able to assemble more than 1,300 mines a day; the Mine Squadron planted as many as 6,820 mines in four hours.

The barrage was not a single wall of mines laid at different levels, but a belt from fifteen to thirty-five miles wide, through which it was exceedingly dangerous for a submarine to go. The surface was more heavily mined than the depths. Mines were planted on three general levels, one making it dangerous for craft on the surface, another making it dangerous for submarines submerged from 90 to 160 feet below the surface, and a third making it dangerous for submarines traveling from 160 to 240 feet below the surface. The barrage

extended from the Norwegian three-mile limit to within ten miles of the Orkney Islands, the inshore unmined channel being heavily patrolled. The planting of the barrage was an international project, the Americans being assigned the work of laying the mines in the deep-water middle sections, and the British in the two shore sections. The Americans, however, laid not only all the mines in their own section, but also over 16,000 mines in the two British sections. The Americans laid 56,611 mines in the Northern Barrage and the British 15,000. The barrage cost about $80,000,000, and it is credited with the sinking of eleven submarines and the damaging of six others.

After the armistice Rear Admiral Strauss, U. S. N., commanded a large force of mine sweepers, submarine chasers, and trawlers in the dangerous work of removing the American mines in the Northern Barrage. Two of the boats were sunk, two officers and six enlisted men killed, several others injured, and fifteen other vessels of the sweeping force were damaged by explosions occurring during this dangerous work. Nevertheless, the American mines were all cleared away by September 30, 1919.

CHAPTER XVII

AIRPLANES

WHEN the United States entered the war against Germany in 1917, there was no phase of her forthcoming industrial effort from which so much was expected as from the building of airplanes and equipment for aërial warfare. Yet there was no phase of the immense undertaking in which the United States was so utterly unprepared. In many other branches of the work of providing *matériel* for a modern army, America, however inadequately acquainted she might be with the developments which had gone on in Europe since 1914, had splendid resources of skill and equipment which could quickly turn from the pursuits of peace to those of war. But there was no large existing industry in the United States which could turn easily to the production of airplanes, for such airplanes as were known in Europe in 1917 had never been built in the United States.

It seems difficult now for us to realize how utterly unlearned we were, both in official and technical quarters, in the design, the production, and the use of aëronautical equipment in those early days of 1917. Here in America mechanical flight had been born; but we had lived to see other nations develop the invention into an industry and a science that were a closed book to our people. In the three years of warfare before American participation, the airplane had been forced through a whole generation of normal mechanical evolution. Of this progress we were aware only as nontechnical and distant observers. Such military study of the progress as we had conducted was casual. It had, in fact, brought to America scarcely a single basic fact on which we could build our contemplated industry.

When the United States became a belligerent no American-

built airplane had ever mounted a machine gun or carried any other than the simplest of necessary instruments. Such things as oxygen apparatus, electrically heated clothing for aviators, radio-communication with airplanes, landing and bombing flares, electric lighting systems for planes, bomb-dropping devices, suitable compasses, instruments for measuring height and speed, and the like,—in short, all the modern paraphernalia that complete the efficiency of combat airplanes,—were almost entirely unknown to us.

The best of the prewar activities of America in this field had produced some useful airplane engines and a few planes which the countries then at war were willing to use in the training of aviators. Within the Army itself there was only a trifling nucleus of skill around which could be built an organization expert and sophisticated. We had in the official files no adequate information as to sizes, capacities, and types of planes or engines, or the sorts of ordnance, armament, and aëronautical appliances demanded by the exacting service in which our young birdmen were soon to engage. Even the airplanes on order in April, 1917 (over 350 of them), proved to be of such antiquated design that the manufacturers, in the light of their increased knowledge of war requirements a few months later, asked to be released from their contracts.

Nor was there in the United States any industry so closely allied to airplane manufacture that its engineers and designers could turn from one to the other and take their places at once abreast of the progress in Europe. There was in the United States little or no engineering talent competent to design fully equipped military aircraft which could compete with Europe. Our aircraft producers must go to France and England and Italy and ground themselves in the principles of a new science before they could attempt to produce their own designs, before they could even be safe in selecting European designs for reproduction in this country.

Sketchy and incomplete as was our knowledge of airplane construction, it was no more hazy than our notion of how many planes to build. What would constitute overwhelming

superiority in the air? As an indication of the rapidity with which history has moved, it may be stated that in January and February of 1917 the Signal Corps discussed the feasibility of building 1,000 planes in a year of construction. This seems to us now a ridiculously low figure to propose as representative of American resources, but in the early weeks of 1917 the construction of a thousand airplanes appeared to be a formidable undertaking. In March, when war was inevitable, we raised this number to 2,500 planes within twelve months; in April, when war was declared, we raised it again to 3,700.

But as soon as we were in the war, and as soon as, through the exchange of military missions, our designers were taken into the confidence of the aviation branches of the French, British, and Italian armies and shown for the first time a comprehensive view of the development of the war plane, including both what had been done in the past and what might be expected in the future, then our Joint Army and Navy Technical Board, in the last week of May and the early part of June, 1917, recommended to the secretaries of War and the Navy that a building program be started at once to produce the stupendous total of 19,775 planes for our own use and 3,000 additional ones if we were to train foreign aviators, or approximately 22,000 in all. This was a program worthy of America's industrial greatness. Of these proposed planes, 7,050 were for training our flyers, 725 for the defense of the United States and insular possessions, and 12,000 for active service in France. Such was the task assigned to an industry that, in the previous twelve months, had manufactured less than 800 airplanes, and those being principally training planes for foreign governments.

The expanding national ambition for an aircraft industry was also shown by the mounting money grants. On May 12 Congress voted $10,800,000 for military aëronautics. On June 15 an appropriation of $43,450,000 was voted for the same purpose. Finally, on July 24, 1917, the President signed the bill appropriating $640,000,000 for aircraft. This was the largest appropriation ever made by Congress for one specific

purpose, and the bill was put through both houses within the period of a little more than a week.

The figure 22,000, however, scarcely indicates the size of this undertaking, as we were to realize before long. We little understood the infinite complications of fully equipping battle planes. Lacking that invaluable experience which Europe had attained in three years of production, we had no practical realization of the fact that for each 100 airplanes an equivalent of 80 additional airplanes must be provided in spare parts. In other words, an effective fighting plane delivered in France is not one plane, but it is one plane and eight-tenths of another; which means that the program adopted in June, 1917, called for the production in twelve months of, not 22,000 airplanes, but rather of the equivalent of 40,000.

Let us set down the inventory of the Government's own resources for handling this project. The American Air Service, then part of the Signal Corps, had had a struggling and meager existence, working with the old pusher type of planes until, in 1914, an appropriation of $250,000 was made available for the purchase of new airplanes and equipment. Shortly after this appropriation was granted, five officers were sent to the Massachusetts Institute of Technology for a course in aëronautics. When the war broke out in Europe in August, 1914, these men constituted the entire technically trained *personnel* of the Air Service of the United States. By April 6, 1917, we had sixty-five officers in the Air Service, an enlisted and civilian *personnel* of 1,330, two flying fields, and a few serviceable planes of the training type. Compare this equipment with that of Germany, France, and England at the time they went to war. Germany is believed to have had nearly 1,000 airplanes in August, 1914; France had about 300; and England barely 250. America's 224, delivered up to April 6, 1917, were nearly all obsolete in type, compared with the machines then in effective service in France.

No sooner had the United States embarked upon the war than the agents of the European manufacturers of airplanes descended upon the Aircraft Board in swarms. France, Eng-

land, and Italy had all adopted the policy of depending upon the private development of designs for their supplies of airplanes, with the result that the builders of each country had produced a number of successful types of flying machines and an even greater number of types of engines. On the assumption that the United States would adopt certain of these types and build them here, the agents for the Sopwiths, the Capronis, the Handley-Pages, and many others proceeded to demonstrate the particular excellences of their various articles. Out of this confusion of counsel stood one pertinent fact in relief—the United States would have to pay considerable royalties for the use of any of these European devices.

As to the relative merits of types and designs, it was soon clear that no intelligent decision could be reached in Washington or anywhere but in Europe. Because of our distance from the front and the length of time required to put the American industrial machine into operation on a large scale, it was necessary that we understand in advance the types and tendencies in aircraft construction, so that we could anticipate aircraft development in such special designs as we might adopt. Otherwise, if we accepted the types of equipment then in use in Europe, by the time we had begun producing on a large scale, a year or so later, we should find our output obsolete, so rapidly was the science of aircraft moving. In June, therefore, the United States sent to Europe a commission of six civilian and military experts, headed by Major R. C. Bolling, part of whose duties was to advise the American War Department as to what types of planes and engines and other air equipment we should prepare to manufacture. Also, in April the Chief of the Signal Corps had sent cables to England, France, and Italy, requesting that aviation experts be sent at once to this country; and shortly after this we dispatched to Europe more than a hundred skilled mechanics to work in the foreign engine and airplane plants and acquire the training that would make them the nucleus of a large mechanical force for aircraft production in this country.

But while these early educational activities were in progress,

much could be done at home that need not await the forthcoming reports from the Bolling mission. We had in this country, for instance, several types of planes and engines suitable for the training fields which were even then being established. The Signal Corps, therefore, bent its energies upon the manufacture of training equipment, leaving the development of battle aircraft to come after we should know more about that subject.

It was evident that we could not equip an airplane industry and furnish machines to our fliers abroad before the summer of 1918; and accordingly we arranged with France for this equipment by placing orders with French factories for 5,875 planes of regular French design. These were all to be delivered by July 1, 1918. In the arrangement with the French factories we agreed to supply from the United States a great deal of the raw materials for these machines, and the contract for furnishing these supplies was given to J. G. White & Company of New York City. This concern did a creditable job, shipping about 5,000,000 feet of lumber, much necessary machinery, and a multitude of items required in the fabrication of airplanes, all to the value of $10,000,000. The total weight of the shipments on this contract was something like 23,000 tons, this figure including 7,500 tons of lumber. The other tonnage consisted of tubing of steel, brass, copper, and aluminum; sheets of steel, copper, lead, and aluminum; and bar steel, tool steel, structural steel, ball bearings, crank shafts, turnbuckles, radiator tubes, wire, cable, bolts, nuts, screws, nails, fiber cloth, felt, and rubber. All this was in addition to approximately 1,000 machine tools, such as motors, lathes, and grinders.

The orders for French planes were divided as follows: 725 Nieuport training planes, 150 Spad training planes, 1,500 Breguet service planes, 2,000 Spad service planes, and 1,500 New Spad or Nieuport service planes. The decision between the New Spad and Nieuport service planes was to be made as soon as the New Spad could be tested. These planes were to be delivered in specified monthly quantities, increasing in number until the total of 1,360 planes should be placed in our

hands during the month of March, 1918, alone. The contracts were to be concluded in June with the delivery of the final 1,115 planes. We also contracted for the manufacture of 8,500 service engines of the Renault, Hispano, and Gnome makes, all of these to be delivered by the end of June.

When the armistice ended the fighting, we had produced a total of 11,754 airplanes in America, together with most of the necessary spare parts for about one-third of them. A large proportion of the American airplanes built in the war period were of the training rather than the service, or battle, type; for it was necessary that we have a large equipment of training planes in order to prepare the swiftly expanding *personnel* of the Air Service for its future activity at the front. The nations associated with us in the war, however, had produced their training equipment in advance of our participation as a belligerent, and at the time we entered the war the French, British, and Italians were producing only enough training planes to maintain their training equipment and were going in heavily, with the rest of their airplane industries, for the production of service planes.

With these considerations in mind, the reader can make an interesting comparison of British and American plane production, the British figures being for both the British Army and the British Navy, whereas the American figures are for the American Army alone. In the following table of comparison the British figures are based on the Lockhart Report of November 1, 1918:

Comparative Rate of Airplane Production—British and United States Army

Calendar year	*British Army and Navy*	*United States Army*
1915, January 1 to December 31	2,040	20
1916, January 1 to December 31	6,000	[1]83
1917, January 1 to December 31	14,400	[2]1,807
1918, January 1 to December 31	30,000	[3]11,950

[1] Experimental.
[2] 1,476 built in last seven months only.
[3] Inclusive of 135 secured by Engineering Department. The American total would have been 12,837 if the October production had continued through November and December.

Broadly interpreted, and without reference to types of planes produced, these figures mean that the United States, in her second year of the war, produced for the American Army alone almost as many airplanes as Great Britain built in her third year of the war for both her army and navy. In October, 1918, factories in this country turned out 1,651 planes, which, without allowing for the monthly expansion in the production, was at the rate of 20,000 planes a year. Assuming no increase in the October rate of production, we should have attained the 22,000 airplanes in twenty-three months after July 1, 1917, the date on which the production effort may be said to have started. Our production of fighting planes in the war period was 3,328.

On the day the armistice was signed we had received from all sources 16,952 planes. Of these, 5,198 had been produced for us by the Allies. We had 48 flying fields, 20,568 air service officers, and 174,456 enlisted men and civilian *personnel*. These figures do not mean that we had more than 17,000 planes on hand at that time, because the mortality in airplanes, from both accidents and ordinary wear and tear, is high.

Photo from Air Service

MANUFACTURING AIRPLANE WINGS

Photo from Air Service

IN THE DAYTON-WRIGHT AIRPLANE FACTORY

Photo from Air Service

WINGS FOR DE HAVILAND PLANES

Photo from Curtiss Aeroplane & Motor Corporation

PANEL DEPARTMENT IN GREAT AIRPLANE FACTORY

THE PROBLEM OF MATERIAL

Once we had started out on this enterprise, we discovered that the production of airplanes was something more than a merely manufacturing job. With almost any other article, we might have made our designs, given orders to the factories, and rested in the security that in due time the articles would be forthcoming. But with airplanes we had to create the industry; and this meant not only the equipping of factories, but the procurement and sometimes the actual production of the raw materials.

For instance, the ideal lubricant for the airplane motor is castor oil. When we discovered that the supply of castor oil was not nearly sufficient for our future needs, the Government secured from Asia a large quantity of castor beans—enough to seed more than 100,000 acres in this country and thus to provide for the future lubrication for our motors. This actual creation of raw materials was conducted on a much larger scale for certain other commodities used in airplane construction, particularly in the production of lumber and cotton and in the manufacture of the chemicals for the "dope" with which the airplane wings are covered and made airtight.

An airplane must have wings and an engine, with a propeller to make it go; and, like a bird, it must have a tail to make it fly straight and a body (fuselage) to hold all together. Part of the tail (the rudder) moves sidewise and steers the airplane from left to right; part (the elevators) moves up and down and makes the airplane go up or down; and parts of the wings (the ailerons) move up and down and make the airplane tip from side to side. All these things must be connected to the controls in the hands of the pilot. The front edges of the wings are raised above the line of flight; and when the propeller driven by the engine forces the wings through the air, the airplane is lifted and flies.

All the airplanes built for the United States during the war were tractor biplanes. In a plane of the tractor type the propeller is in front and pulls the machine. The biplane is so called because it has two planes or wings, one above the other.

Of all types the biplane has been the most largely used in war, for two reasons: first, the struts and wires between the planes form a truss structure, and this gives the needed strength; secondly, there is less danger of enemy bullets wrecking a biplane in the air, because its wing support is greater than that of the monoplane, or single-winged, machine.

Since the airplane can lift only a limited weight, every part of the mechanism must be as light as possible. An airplane engine weighs from two to three pounds to the horsepower, whereas an automobile motor weighs from eight to ten. The skeleton of the airplane is made of wood, mostly spruce, with sheet-steel fittings to join the wood parts together, and steel wires and rods to make every part a truss. This skeleton is covered with cloth, and the cloth is stretched and made smooth by dope.

Wood, sheet steel, wire, cloth, varnish—these are the principal components of an airplane. As raw materials, they all seem easy to obtain in America. And so they are, in peace times and for ordinary purposes. But never before had quality been so essential in an American industry, from the raw material up to the finished product—quality in the materials used, and quality in the workmanship which fashions the parts. Moreover, we were forced to produce in quantities bounded only by our own physical limitations; and these quantities must include not only the materials for our own air program, but also some of the principal raw materials used by the airplane builders in France and England—specifically, all the spruce which the Allies would require and, later, much of the wing fabric and dope for their machines. It was early evident to us that we had on our hands a problem in spruce production which the Government itself must solve, if the airplane undertaking were not to fail at the outset. When we entered the war, linen was exclusively used for the covering of wings; and it transpired almost immediately that the United Kingdom was practically the sole source of linen. But the Irish looms could not begin to furnish us with our needs for this commodity. Later on there arose the question of sup-

plying dope and castor oil. Finally, during the last months of the war, it became necessary for us to follow up the production of all classes of our raw material, particularly by working out a suitable supply of steel tubing. But our great creative efforts in raw materials were confined to spruce, fabric, and dope.

The lumber problem involved vast industrial and technical questions. We had to conduct a campaign of education in the knowledge of aircraft requirements; a campaign that reached from the loggers in the woods to the sawmill men, to the cut-up plants, and then followed through the processes of drying and sawing to the proper utilization of the lumber in the aircraft factories. In working out these problems, though we drew heavily upon the experience of Europe, we added our own technical skill to the solution. The Signal Corps was assisted by the Forest Products Laboratory at Madison, Wisconsin, and by the wood section of the inspection department of the Bureau of Aircraft Production. The United States Forest Service contributed its share of technical knowledge. At the end of the war we considered that our practice in the handling of aircraft lumber was superior to that of either France or England.

THE SPRUCE PROBLEM

Each airplane uses two distinct sorts of wood—first, the spruce or similar lumber for the wing beams or other plane parts; secondly, mahogany, walnut, or some other hardwood for the propeller. The army production authorities were involved in securing both kinds of lumber, and also in educating manufacturers to handle it properly.

In an ordinary biplane there are two beams for each lateral wing, eight beams to the plane. These form the basis of strength for the wings. Because of the heavy stresses put upon the airplanes by battle conditions, only the most perfect and straight-grained wood is suitable for these beams. All cross-grained or spiral-grained material, or material too coarse in structure, is useless.

Spruce is the best of all woods for wing beams. Our problem was to supply lumber enough for the wing beams, disregard-

ing the other parts; for all other wood used in the manufacture of planes could be secured from cuttings from the wing-beam stock. At the beginning we built each beam out of one piece of wood; and this meant that the lumber must be extra long, thick, and perfect. Until we learned how to cut the spruce economically we found that only a small portion of the lumber actually logged was satisfactory for airplanes. A biplane of average size uses less than 500 feet of lumber. In the hands of skilled cutters this quantity can be worked out of 1,000 feet of rough lumber. But in the earlier days of the undertaking as high as 5,000 feet of spruce were used up for a single plane, because of imperfections in the lumber, lack of proper inspection at the mills, and faulty handling in transit and in the factories. We also used certain species of fir in building training planes. This wood, like spruce, is light, tough, and strong. The only great source of supply of these woods was in the Pacific Northwest, although there was a modest quantity of suitable timber in West Virginia, North Carolina, and New England.

At first we expected to rely upon the unaided efforts of the lumber producers. But labor difficulties almost immediately arose in the Northwest, and they hindered the production of lumber. The effort, too, was beset with physical difficulties; for the large virgin stands of spruce occurred only at intervals and often at long distances from the railroads. By the middle of October, 1917, it became evident that the northwestern lumber industry, unaided, could not deliver the spruce and fir; and the Chief of Staff of the Army formed a military organization to handle the situation. On November 6, 1917, Colonel Brice P. Disque took command of the Spruce Production Division of the Signal Corps, this organization later being transferred to the Bureau of Aircraft Production. When Colonel Disque went into the Northwest he found the industry in a chaotic condition. The I. W. W. was demoralizing the labor forces. The mills did not have the machinery to cut the straight-grained lumber needed, and their timber experts were not sufficiently skilled in the selection and judging of logs

to secure the maximum footage. The whole industry was organized for quantity production, and it had no interest in the high quality requirements insisted upon by the Government.

One of the first acts of the military organization was to organize a society called the Loyal Legion of Loggers and Lumbermen, the "L. L. L. L.," to offset the I. W. W. propaganda, on a platform of no strikes, fair wages, and the conscientious production of the Government's requirements. On March 1, 1918, 75,000 lumbermen and operators agreed without reservation to give Colonel Disque power to decide all labor disputes. The specifications for logs were then standardized and modified as far as was practicable in the direction of meeting the manufacturers' needs. We arranged financial assistance, that they might equip their mills with the proper machinery. We instituted a system of instruction for the *personnel.* Finally, the Government fixed a price for aircraft spruce that stabilized the industry and provided against delays from labor disputes.

While these basic reforms were being instituted, our organization had energetically taken up the physical problems relating to the work. We surveyed the existing stands of spruce timber, built railroads connecting them with the mills, and projected other railroads far into the future. We began and encouraged logging by farmers in small operations. By these and other methods, the efficiency of this production effort gradually increased. In all, we took 180,000,000 feet of aircraft lumber out of the northwestern forests. To the Allies went 120,000,000 feet; to the United States Army and Navy, 60,000,000 feet.

Even when we had resolved the difficulties in the forests, only part of the problem had been met. Next came the intricate industrial question of how to prepare this lumber for aircraft use. We possessed little knowledge of the proper methods of seasoning it. The vast majority of woodworking plants in this country, such as those for furniture and pianos, had always dried lumber to the end that it might keep its shape. We were now faced with the technical question of drying lumber so as

to preserve its strength. The Forest Products Laboratory worked out a scientific method for this sort of seasoning. Incidentally, they discovered that ordinary commercial drying had seldom been carried on scientifically. The country received a lasting benefit from this instruction, carried broadcast over the woodworking industries.

In the progress of our wood studies we discovered a method of splicing short lengths of spruce to make wing beams; and in the later months of the production we used these spliced beams exclusively, at a great saving in raw materials. In another year of warfare the use of laminated beams would probably have become universal.

COTTON FABRIC AND DOPE

The flying surfaces of an airplane are made by stretching cloth over the frames. When we came into war it was supposed that linen was the only common fabric with sufficient strength for this use, and linen was almost exclusively used by the airplane builders, although Italian manufacturers were trying to develop a cotton fabric. Of the three principal sources of flax, Belgium had been cut off from the Allies, Russia was isolated entirely after the revolution there, and Ireland was left as the sole available land from which flax for airplane linen could be obtained. As late as August, 1917, England assured us that she could supply all the linen that would be needed. It rapidly became evident that England had underestimated our requirements. An average airplane requires 250 yards of fabric; some of the large machines need more than 500 yards. And these requirements do not take into consideration the spare wings which must be supplied with each airplane. This meant a demand for millions of yards put upon the Irish supply, which had no such surplus above Allied needs.

For some time before April 6, 1917, the Bureau of Standards at Washington had been experimenting with cotton airplane cloths. Out of the large variety of fabrics tested, several promising experimental cloths were produced. The chief objection to cotton was that the dope which gave satisfactory

results on linen failed to work with uniformity on cotton. Therefore it became clear that, if we were to use cotton fabric, we should also have to invent a new dope.

Two grades of cotton airplane cloth were finally evolved—A, which had a minimum strength of eighty pounds to the inch, and B, with a minimum strength of seventy-five pounds to the inch. Grade A was later universally adopted. This cloth weighed four and one-half ounces to the square yard. We placed our first orders for cotton airplane fabric in September, 1917,—orders for 20,000 yards,—and from that time on, the use of linen decreased. By March of 1918 the production of cotton airplane cloth had reached 400,000 yards a month. In May the production was about 900,000 yards; and when the war ended, this material was being turned out at the rate of 1,200,000 yards a month. Starting with a few machines, our cotton mills had gradually brought 2,600 looms into the enterprise, each loom turning out about 120 yards of cloth in a week. A total of 10,248,355 yards of cotton fabric was woven and delivered to the Government—over 5,800 miles of it, nearly enough to reach from California to France. The use of cotton fabric so expanded that in August, 1918, we discontinued the importations of linen altogether. There was, however, danger that we should be limited in our output of cotton fabric if there were any curtailment in the supply of the long-staple sea-island and Egyptian cotton of which this cloth is made. To make sure that there should be no shortage of this material, the Signal Corps went into the market in November, 1917, and purchased 15,000 bales of sea-island cotton. This gave us at all times an adequate reserve of raw material for the new fabric.

Thus, just as the airplane situation had been saved by the prompt action of the Signal Corps in organizing and training the spruce industry, so again the uninterrupted expansion of the Allied aviation program was made possible by the decision to produce cotton fabric and by prompt action in cornering the supply. Cotton proved to be not only an admirable substitute for linen, but actually a better fabric. No matter how

abundant the supply of flax may be, it is unlikely that linen will ever again be used in large quantities for the manufacture of airplane wings.

Not only must the wings of an airplane be covered with fabric, but the fabric must be filled with dope, which is a sort of varnish. The function of the dope is to stretch the cloth tight and to create on it a smooth surface. After the dope is on the fabric the surface is protected further by a coat of ordinary spar varnish.

We found in the market two sorts of dope which were being furnished to airplane builders of all countries by various chemical and varnish manufacturers. One, nitrate in composition, was made from nitrocellulose and certain wood-chemical solvents, including alcohol. This produced a surface similar to that of a photographic film. The other kind of dope had an acetate base and was made from cellulose-acetate and such wood-chemical solvents as acetone. The nitrate dope burned rapidly when ignited, but the acetate type was slow-burning. Therefore the nitrate dope would be fairly satisfactory in training planes not subject to attack by enemy incendiary bullets, but in the fighting planes the slow-burning acetate dope was a vital necessity. Up to the time of our participation in the war, the dopes produced in the United States were principally nitrate. It was evident that, to avoid the danger of fire, we must make our new dope acetate in composition. But for this we should require great quantities of acetone and acetate chemicals; and a careful canvass of the supply of such ingredients showed that it would be impossible for us to obtain these in anything like the necessary quantities without developing quite new sources of production.

Already acetone and its kindred products were being absorbed in large quantities by the war production of the Allies. The British Army was absolutely dependent upon cordite as a high explosive. Acetone is the chemical basis of cordite; and therefore the British Army looked with great concern upon the added demand which the American aviation program proposed to put upon the acetone supply. We estimated that in


Photo from Air Service

SEAMING FABRIC FOR WINGS


Photo from Air Service

ASSEMBLING ENGINES IN FUSELAGES

Photo from Air Service

APPLYING DOPE TO WING FABRIC

Photo from Air Service

BUILDING FUSELAGES AT CURTISS PLANT

1918 we should require 25,000 tons of acetone in our dope production. The British war mission in this country submitted figures showing that the war demands of the Allies, together with their necessary domestic requirements, would in themselves be greater than the total world production of acetone.

There was nothing, then, for us to do but to increase the source of supply of these necessary acetate compounds; and this was done by encouraging, financially and otherwise, the establishment of ten large chemical plants, located in as many towns and cities, as follows: Collinwood, Tennessee; Tyrone, Pennsylvania; Mechanicsville, New York; Shawenegan Falls, Canada; Kingsport, Tennessee; Lyles, Tennessee; Fremont, Missouri; Sutton, West Virginia; Shelby, Alabama; and Terre Haute, Indiana.

But it was evident that before these plants could be completed the airplane builders would be needing dope; and therefore steps were taken to keep things going in all the principal countries fighting Germany until the acetate shortage could be relieved. In December, 1917, we commandeered all the existing American supply of acetate of lime, the base from which acetone and kindred products are made. Then we entered into a pool with the Allied governments to ration these supplies of chemicals, pending the era of plenty. Our agency in this pool was the wood-chemical section of the War Industries Board; the Allies placed their demands in the hands of the British war mission. These two boards allocated the acetate chemicals among the different countries according to the urgency of their demands. Since it was evident there might be financial losses incurred as the result of the commandeering order or in the project of the new government chemical plants, the British war mission agreed that any deficit should be shared equally by the American and British governments. It was also agreed that we should not have any advantage in prices paid for acetates of American origin. Under this arrangement we were able to produce 1,324,356 gallons of fabric dope during the period of hostilities, without upsetting any of the European

war-production projects. Had the war continued, the output from the ten chemical plants in which the Government was a partner would have cared for all American and Allied requirements, allowing the production of private plants to go exclusively for the ordinary commercial purposes.

THE TRAINING PLANES

The actual building of the airplanes furnished a striking example of the value of previous experience, either direct or of a cognate sort, in the quantity production of an article. What airplanes we had built in the United States—and the number was small, being less than 800 in the twelve months prior to April, 1917—had been entirely of the training type. These had been produced principally for foreign governments. But this slight manufacture gave us a nucleus of skill and equipment that we were able to expand to meet our own training needs almost as rapidly as fields could be equipped and student aviators enlisted. The training-plane program can be called a success, as the final production figures show. Of the 11,754 airplanes actually turned out by American factories, 8,567 were training machines. This was close to the 10,000 mark set as our ambition in June, 1917.

There are two types of training planes—those used in the primary instruction of students and those in the advanced teaching, the latter approaching the service planes in type. The primary plane carries the student and the instructor. Each occupant of the fuselage has before him a full set of controls, so interconnected that the instructor at will can do the flying himself, or correct the student's false moves, or allow the student to take complete charge of the machine. These primary planes fly at the relatively slow average speed of seventy-five miles an hour, and they require engines so reliable as to need little attention.

For our training planes we adopted the Curtiss JN–4, with the Curtiss OX–5 engine, and, as a supplementary equipment, the Standard Aero Corporation's J–1 plane, with the Hall-Scott "A7A" engine. Both these planes and both engines had

been previously manufactured here. The Curtiss equipment, which was the standard at our training camps, gave complete satisfaction. The J–1 plane was later withdrawn from use, partly because the plane itself was not liked, partly because of the vibration resulting from the Hall-Scott engine (which had only four cylinders), and partly because of the uncertainty of the engine in cold weather.

It was evident that at the first we must turn our entire manufacturing capacity to the production of training planes. We should need these first in any event, and we were not yet equipped with the knowledge to enable us to make intelligent selections of service types.

In taking up the manufacturing problem, the first step was to divide the existing responsible airplane plants between the Army and the Navy, following the general rule that a single plant should confine its work to the needs of one government department only. There were, of course, exceptions to this rule. The division made gave the Army the plants of the Curtiss Aeroplane & Motor Corporation, Buffalo, New York; the Standard Aircraft Corporation, Elizabeth, New Jersey; the Thomas-Morse Aircraft Corporation, Ithaca, New York; the Wright-Martin Aircraft Corporation, Los Angeles, California; and the Sturtevant Aeroplane Company, Jamaica Plain, Massachusetts.

The factories which fell to the Navy were those of the Curtiss Aeroplane & Motor Corporation, Buffalo, New York; the Burgess Company, Marblehead, Massachusetts; L. W. F. (Lowe, Willard & Fowler) Engineering Company, College Point, Long Island; the Aeromarine Plane & Motor Company, Keyport, New Jersey; the Gallaudet Aircraft Corporation, New York; and the Boeing Airplane Company, Seattle, Washington. Of these concerns, Curtiss, Standard, Burgess, L. W. F., Thomas-Morse, and Wright-Martin were the only ones which had ever built more than ten machines.

These factories were quite insufficient in themselves to carry out the enterprise. Other airplane plants must be created. Two new factories thereupon sprang into existence under govern-

ment encouragement. The largest producer of automobile bodies was the Fisher Body Company, at Detroit, Michigan. The manufacture of automobile bodies is akin to the manufacture of airplanes to the extent that each is a fabrication of accurate, interchangeable wood and sheet-steel parts. The Fisher organization brought into the enterprise not only machinery and buildings, but also a skilled organization trained in such production on a large scale. At Dayton, Ohio, the Dayton-Wright Airplane Corporation was created. With this company was associated Orville Wright, and its engineering force was built up around the old Wright organization. A number of immense buildings which had been recently erected for other purposes were at once utilized in this new undertaking.

As an addition to these two large sources of supply, J. G. White & Company and J. G. Brill & Company, the well-known builders of street cars, formed the Springfield Aircraft Corporation at Springfield, Massachusetts. Also, certain forward-looking men on the Pacific coast created in California several airplane plants, some of which ultimately became satisfactory producers of training planes.

At this point in the development we were not aware of the great production of spare parts that would be necessary. Yet we did understand that there must be a considerable production of spares; and in order to take the burden of this manufacture from the regular airplane plants, and also to educate other factories up to the point at which they could undertake the construction of complete airplanes, we placed many contracts for spare parts with widely scattered concerns. Among the principal producers of spares were the Metz Company, Waltham, Massachusetts; the Sturtevant Aeroplane Company, Jamaica Plain, Massachusetts; the Wilson Body Company, Bay City, Michigan; the West Virginia Aircraft Corporation, Wheeling, West Virginia; the Rubay Company, Cleveland, Ohio; the Engel Aircraft Company, Niles, Ohio; and the Hayes-Ionia Company, Grand Rapids, Michigan.

For a long time the supply of spare parts was insufficient for

the needs of the training fields. This was only partly due to the early lack of a proper realization of the quantity of spares that would be required. The production of spares on an adequate scale was hampered by numerous manufacturing difficulties incident to new industry of any sort in shops unacquainted with the work, and by a lack of proper drawings for the parts.

Production of Training Planes

	Primary training planes, SJ-1, JN-4D, Penguin	*Advanced training planes, JN-4 and 6H, S-4B and C, E-1, SE-5*
1917		
April	...	...
May	...	...
June	9	...
July	56	...
August	103	...
September	193	...
October	340	...
November	331	1
December	423	20
1918		
January	700	29
February	526	199
1918 (cont.)		
March	756	178
April	645	81
May	419	166
June	126	313
July	236	427
August	296	193
September	233	132
October	212	320
November	186	297
December	162	259
Total	5,952	2,615

As to the training planes themselves, with all factories in the country devoting themselves at the start to this type exclusively, the production soon attained great momentum. The Curtiss Company, in particular, produced training planes at a pace far beyond anything previously attained. The maximum production of JN–4 machines was reached in March, 1918, when 756 were turned out.

Advanced training machines are faster, traveling at about 105 miles an hour; and they carry various types of equipment to train observers, gunners, photographers, and radio men. For this machine we adopted the Curtiss JN–4H, which was sub-

stantially the same as the primary training plane except that it carried a 150-horsepower Hispano-Suiza engine. We also built a few "penguins," a kind of half airplane that never leaves the ground; but this French method of training with penguins we never truly adopted.

The finishing school for our aviators was in France, where the training was conducted in Nieuports and other fighting machines.

In July, 1918, we reached the maximum production of the advanced training machines, the output being 427. As the supply of primary training planes met the demands of the fields, the production was reduced. The original equipment, kept up by only enough manufacture to produce spares and replacement machines, would suffice to train all the aviators we should need.

THE SERVICE PLANES

It was not until we took up the production of fighting, or service, airplanes that we came to a full realization of the magnitude of the engineering and manufacturing problems involved. We had perhaps a dozen men in the United States who knew something about the designing of flying machines, but not one in touch with the development of the art in Europe or competent to design a complete fighting airplane. We had the necessary talent to produce designs and conduct the manufacture of training planes; but at the outset, at least, we were unwilling to attempt designs for service planes on our own initiative. At the beginning we were entirely guided, as to types of fighting machines, by the Bolling mission in France.

In approaching this, the more difficult phase of the airplane problem, our first act was to take an inventory of the engineering plants in the United States available for our purposes. With the Curtiss Company were Glenn Curtiss, a leader of airplane design, and several competent engineers. The Curtiss Company had been the largest producers in the United States of training machines for the British, had had the benefit of assistance

from British engineers, and therefore possessed more knowledge and experience to apply to the service-plane problem than any other company. For this reason we selected this plant to duplicate the French Spad plane, the story of which undertaking will be told further on. Orville Wright, the pioneer of flying, though not in the best of health, was devoting his entire time to experimental work in Dayton. Willard, who had designed the L. W. F. airplane and was then with the Aeromarine Company; Charles Day, formerly with the Sloane Manufacturing Company, and then with the Standard Aircraft Corporation; Starling Burgess, with the Burgess Company, of Marblehead, Massachusetts; Grover C. Loening, of the Sturtevant Company; and D. D. Thomas, with the Thomas-Morse Company, were all aviation engineers on whom we could call. One of the best experts of this sort in the country was Lieutenant Commander Hunsaker, of the Navy. In the Signal Corps we had Captain V. E. Clark, who was also an expert in aviation construction, and he had several able assistants under him. The Burgess factory at Marblehead, the Aeromarine plants at Nutley and Keyport, New Jersey, and the Boeing Airplane Company at Seattle were to work exclusively for the Navy, according to the mutual agreement, taking their aëronautical engineers with them. This gave the Army the engineering resources of the Curtiss, Dayton-Wright, and Thomas-Morse companies.

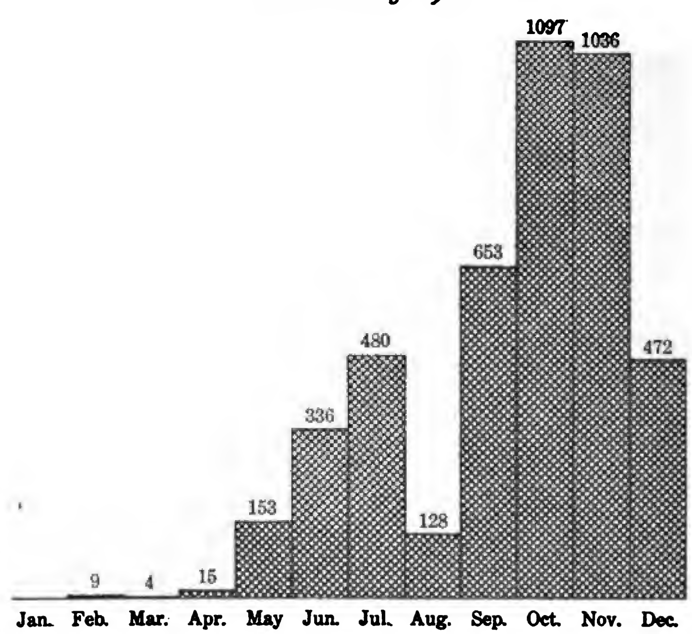
We early decided to give precedence in this country to the observation type of service plane, eliminating the single-place fighter altogether and following the observation planes as soon as possible with production of two-place fighting machines. This decision was based on the fact, not always generally remembered, that the primary purpose of war flying is observation. The duels in the air that occurred in large numbers, especially during the earlier stages of the war, were primarily to protect the observation machines or to prevent observation by enemy machines.

The first service plane which we put into production—it proved to be the main reliance of our service-plane program—

was the De Haviland–4, which is an observation two-place airplane propelled by a Liberty 12-cylinder engine. As soon as the Bolling mission began to recommend types of service machines, it sent samples of the planes thus recommended. The sample De Haviland was received in New York on July 18, 1917. After it had been studied by various officers it was sent

FIGURE 16

De Haviland–4 Airplanes Produced Each Month during 1918



to Dayton. It had reached us without engine, guns, or armament, and also without many other accessories later recommended as essential to a fighting machine. Before we could begin any duplication, the plane had to be redesigned to take our machine guns, our instruments, and our other accessories, as well as our Liberty engine. The preliminary designing was

completed, and the first American-built De Haviland model was ready to fly on October 29, 1917.

Figure 16 does not tell quite the complete story of De Haviland production, for in August and September 204 De Haviland planes which had been built were shipped to France without engines and were there knocked down to provide spare parts for other De Havilands in service. These 204 machines, therefore, do not appear in the production total. Adding them to the figures above, we find that the total output of De Haviland airplanes up to the end of December, 1918, was in number 4,587.

The production of the model machine only served to show us some of the problems which must be overcome before we could secure a standard design that could go into quantity production. Experimental work on the De Haviland continued during December, 1917, and January and February, 1918. The struggle—for it was a struggle—to secure harmony between this English design and the American equipment which it must contain ended triumphantly on the 8th day of April, 1918, when the machine known as No. 31 was completely finished and established as the model for the future De Havilands. The characteristics of the standard American De Haviland-4 were as follows:

Endurance at 6,500 feet, full throttle, 2 hours, 13 minutes
Endurance at 6,500 feet, half throttle, 3 hours, 3 minutes
Ceiling, 19,500 feet
Climb to 10,000 feet (loaded), 14 minutes
Speed at ground level, 124.7 miles
Speed at 6,500 feet, 120 miles
Speed at 10,000 feet, 117 miles
Speed at 15,000 feet, 113 miles
Weight, bare plane, 2,391 pounds
Weight, loaded, 3,582 pounds

("Endurance" here means the length of time the fuel supply will last. The "ceiling" is the maximum altitude at which the plane can be maneuvered in actual service. "Ground level" means only far enough above the ground to be clear of obstructions.)

The first De Havilands to arrive in France were immediately put together, such remediable imperfections as existed were corrected then and there, and the machines were flown to the training fields. The changing and increasing demands of the service indicated the advisability of certain changes of design. The foreign manufacturers had brought out a covering for the gasoline tanks which made them nearly leak-proof, even when perforated by a bullet. In the first De Havilands the location of the principal gas tanks between the pilot and the observer was not the best arrangement: the men were too far apart from each other, and if the machine went down, the pilot would be crushed by the gas tank. Also, the radius of action was not considered to be great enough, even though the later machines of this type carried eighty-eight gallons of gasoline.

The American aircraft designers thereupon brought out an improved De Haviland, known as the 9–A. This carried a Liberty–12 engine; and the main differences between it and the De Haviland–4 were new locations for pilot and tanks (their positions being interchanged), increased gasoline capacity, and increased wing surface. The machine was a cleaner, more finished design; it showed slightly more speed and had a greater radius of action than the De Haviland–4, which it was planned to succeed. We ordered 4,000 of the new machines from the Curtiss Company, but the armistice cut short this production.

The difficulties in the way of producing new service planes on a great scale without previous experience in such construction are clearly shown in the attempts we made to duplicate other successful foreign planes. On September 12, 1917, we received from the aviation experts abroad a sample of the French Spad. Having been previously advised to go into a heavy production of this model, we had made arrangements for the Curtiss Company at Buffalo to undertake the work. This development was well under way when, in December, a cablegram from General Pershing advised us to leave the production of all single-place fighters to Europe. We canceled the

Photo from Air Service

THE U. S. DE HAVILAND 9-A

Photo from Air Service

AIRPLANES READY FOR SHIPMENT FROM FACTORY

Photo from Navy Department

STENCILING INSIGNIA ON WING PANELS

Photo by International Film Service

AIRPLANES ON TEXAS FLYING FIELD

Spad order, and thereafter attempted to build no single-place pursuit planes. At the time, this course seemed to be justified. The day of the single seater seemed to be over. The lone occupant of the single seater can not keep his attention in all directions at once; and as the planes grew thicker in the air, the casualties among fliers increased. But the development of formation flying restored the single-place machine to favor. The formation had no blind spot, and it removed the principal objection to the single seater. The end of the war found the one-man airplane more useful than ever. Our concentration here, however, was upon two-place fighters.

On August 25, 1917, we received from abroad a sample of the Bristol fighting plane, a two-seat machine. The government engineers at once began redesigning this machine to take the Liberty–12 engine and the American ordnance and accessories. The engine which had been used in the Bristol plane developed 275 horsepower. We proposed to equip it with an engine developing 400 horsepower. The Bristol undertaking was not successful. The fact that, later in the airplane program, American designers successfully developed two-seater pursuit planes around the Liberty–12 engine shows that the change of engines was not the cause of the failure. There were repeated changes in the engineering management of the Bristol job. First the government engineers alone undertook it; then the government engineers combined with the drafting force of the airplane factory; finally the Government placed on the factory the entire responsibility for the job, without, however, permitting the manufacturer to correct any of the basic principles involved. On the whole the development of an American Bristol was most unsatisfactory, and the project was definitely abandoned in June, 1918.

The fundamental difficulty in all these attempts was that we were trying to fit an American engine to a foreign airplane, instead of building an American airplane around an American engine. It was inevitable that this difficulty should arise. We had skill to produce a great engine, and we did so; but for our planes for this engine we relied upon foreign

models until we were sufficiently advanced in the art to design for ourselves. We were successful in making the adaptation only with the De Haviland, and then only after great delay. But eventually we were to see some brilliantly successful efforts to design a two-place fighter around the Liberty–12. We had need of such a mechanism to supplement the De Haviland observation-plane production and make a complete service-plane program.

On January 4, 1918, Captain Lepere, a French aëronautical engineer, who had formerly been with the French Government at St. Cyr, began experimental work on a new plane at the factory of the Packard Motor Car Company. By May 18 his work had advanced to a stage where the Government felt justified in entering into a contract with the Packard Company to provide shop facilities for the production of twenty-five experimental planes under Captain Lepere's direction. The result of these efforts was a two-place fighting machine built around a Liberty engine. From the start this design met with the approval of the manufacturer and engineers, because of its clean-cut perfection.

Performance of Lepere Service Plane

	Climb			Speed	
Altitude	*Time*		*R.P.M.**	*Miles an hour*	*R.P.M.**
	min.	*sec.*			
Ground . . .	0	0	1,500	136	1,800
10,000 feet . .	10	35	1,520	132	1,740
15,000 feet . .	19	15	1,500	118	1,620
20,000 feet . .	41		1,480	102	1,550

* R. P. M. = revolutions made by propeller in a minute.

Here at last was a machine that performed brilliantly in the air and contained great possibilities for quantity production, because it was designed from the start to fit American manufacturing methods. We placed orders for 3,525 Lepere machines. None of the factories, however, had come into pro-

duction with the Lepere on November 11, 1918. Seven sample machines had been turned out and put through every test. It was the belief of those in authority that at last the training and technique of the best aëronautical engineers of France had been combined with the Liberty, probably the best of all aërial engines; and it was believed that the spring of 1919 would see the Yankee fliers equipped with American fighting machines superior to anything they would be required to meet. Nor were these expectations without justification. The weeks and months following the declaration of the armistice and extending through to the spring of 1919 were to witness the birth of a whole brood of new, typically American designs of airplanes, of which the Lepere was the forerunner. In short, when the armistice brought the great aviation enterprise to an abrupt end, the American industry had fairly caught that of Europe, and American designers were ready to match their skill against that of the master builders of France, Great Britain, Italy, and the Central Powers.

The Lepere two-seated fighter was quickly followed by two other Lepere models—one of them, known as the Lepere C-21, being armored and driven by a Bugatti engine, the other a triplane driven by two Liberty engines and designed to be a day bomber. Then the first American-designed single-seat pursuit planes began making their appearance—the Thomas-Morse pursuit plane, its 164 miles an hour at ground level making it the fastest airplane ever tested by our Government, if not the fastest ever built; the Ordnance Engineering Corporation's Scout, an advanced training plane; and several others. In two-seater fighting planes there was the Loening monoplane, an extremely swift and advanced type. There were several other new two-seaters, designed experimentally in some instances, and some of them giving roseate promise.

Perhaps the severest and most exacting critic of aviation material is the aviator who has to fly the plane and fight with the equipment at the front. Brigadier General William Mitchell, then a colonel, was sent to France in 1917. He became, in succession, Chief of the Air Service of the First Army

Corps, Chief of the Air Service of the First Army, and finally Chief of the Air Service of the American group of armies in France. He commanded the aërial operations at the reduction of the St. Mihiel salient, where he gained the distinction of having commanded more airplanes in action than were ever assembled before under a single command. At St. Mihiel there were 1,200 Allied planes in action, including, with our own, French, English, and Italian planes. General Mitchell, therefore, spoke as a high authority on the merits of air equipment from the airman's standpoint. In the spring of 1919, after a thorough investigation of the latest types of American planes and aërial equipment at the Wilbur Wright Field at Dayton, he sent to the Director of Air Service, Washington, D. C., the following telegram under the date April 20:

> I recommend the following airplanes in the numbers given be purchased at once: 100 Lepere 2-place corps observation, 50 Loening 2-place pursuit, 100 Ordnance Engineering Corporation 1-place pursuit, 100 Thomas-Morse 1-place pursuit, 50 USD9–A day bombardment, 700 additional Hispano-Suiza 300-horsepower engines, 2,000 parachutes. All of the above types are the equal of or better than anything in Europe.
>
> MITCHELL.

Let us examine some of the specifications and performances of these new models. The USD9–A, the redesigned and improved De Haviland–4, was a two-place bombing plane of the tractor biplane type, equipped with a Liberty–12 engine and weighing 4,872 pounds when loaded with fuel, oil, guns, and bombs and with its crew aboard. With this weight its performance record in the official tests at Wilbur Wright Field in Dayton was as follows:

Speed (miles per hour):	
At ground	121.5
At 6,500 feet	118.5
At 10,000 feet	115.5
At 15,000 feet	95.5

Climb:

To 6,500 feet	11 minutes, 40 seconds
To 10,000 feet	19 minutes, 30 seconds
To 15,000 feet	49 minutes
Service ceiling	14,400 feet

The Lepere C–11, a tractor biplane equipped with a Liberty–12 engine, Packard make, weighing with its load aboard 3,655 pounds, performed as follows in the tests at the Wilbur Wright Field:

Speed (miles per hour):

At ground	136
At 6,500 feet	130
At 10,000 feet	127
At 15,000 feet	118

Climb:

To 6,500 feet	6 minutes
To 10,000 feet	10 minutes, 35 seconds
To 15,000 feet	19 minutes, 15 seconds
Service ceiling	21,000 feet
Endurance at full speed at ground	2.5 hours

The Lepere carried two Marlin guns synchronized with the propeller and operated by the pilot, and two Lewis guns operated by the observer. A total of 1,720 rounds of ammunition was carried.

The Loening monoplane, a tractor airplane equipped with an Hispano-Suiza 300-horsepower engine and representing, loaded, a gross weight of 2,680 pounds, its military load including two Marlin and two Lewis machine guns, performed as follows at the Wilbur Wright Field:

Speed (miles per hour):

At ground	143.5
At 6,500 feet	138.2
At 10,000 feet	135
At 15,000 feet	127.6

Climb:	
To 6,500 feet	5 minutes, 12 seconds
To 10,000 feet	9 minutes, 12 seconds
To 15,000 feet	18 minutes, 24 seconds
Service ceiling	18,500 feet

The Ordnance Scout with a Le Rhone 80-horsepower engine, weighing, loaded, 1,117 pounds, was an advanced training plane. In its official test at Wilbur Wright Field it performed as follows:

Speed (miles per hour):	
At 6,500 feet	90
At 10,000 feet	83.7
At 15,000 feet	69.8
Climb:	
To 6,000 feet	8 minutes, 30 seconds
To 10,000 feet	17 minutes, 40 seconds
To 14,000 feet	43 minutes, 20 seconds

The Thomas-Morse MB–3 pursuit plane, a tractor biplane equipped with an Hispano-Suiza 300-horsepower engine, weighing, including its crew, but without military load, 1,880 pounds, in unofficial tests at Wilbur Wright Field performed as follows:

Speed at ground level (miles per hour) .	163.68
Climb to 10,000 feet	4 minutes, 52 seconds

This plane was armed with two Browning machine guns synchronized with the propeller and carried 1,500 rounds of ammunition.

Uncertain as we originally were as to types of pursuit and observation planes to produce in this country, we were still more uncertain as to designs of night-bombing machines. These relatively slow weight-carrying planes were big and required the motive power of two or three engines, with the complications attendant upon double or triple power plants. They really presented the most difficult manufacturing problem

which we encountered. Until the summer of 1918 there were only two machines of this type which we could adopt, the Handley-Page and the Caproni. We put the Handley-Page into production, not necessarily because it was as perfect as the Caproni, but because we could get the drawings for it and could not get the drawings for the Caproni, owing to complications in the negotiations for the right to construct the Italian airplane. We were not entirely satisfied with the decision to build Handley-Pages, because its ceiling, or maximum working altitude which it could attain, was low; and, twelve months later, when we were in production, we might find the Handley-Pages of doubtful value because of the ever-increasing ranges of anti-aircraft guns.

We secured a set of drawings, supposed to be complete, for the Handley-Page in August, 1917; but twice during the following winter new sets of drawings were sent from England, and few, if any, of the parts as designed in the original drawings escaped alteration. The Handley-Page had a wing spread of over 100 feet. It was evident from the start that the fuselage, wings, and other large parts of such a machine could not be assembled in this country for shipment complete to Europe. We decided to manufacture the parts in this country and assemble the machines in England, the British air ministry in London having entered into a contract for the creation of an assembling factory at Oldham, England, in the Lancashire district. When it is realized that each Handley-Page involved 100,000 separate parts, something of the magnitude of the manufacturing job can be understood. And after they were manufactured, these parts, particularly the delicate members made of wood, had to be carefully packed if they were to reach England in good condition. The packing of the parts was in itself a problem.

We proposed to drive the American Handley-Page with two Liberty–12 engines. The fittings, extremely intricate pieces of pressed steel work, were practically all to be produced by the Mullins Steel Boat Company at Salem, Ohio. Contracts for the other parts were placed with the Grand Rapids Air-

plane Company, a concern which had been organized by a group of furniture makers at Grand Rapids, Michigan. All the parts were to be brought together, previously to ocean shipment, in a warehouse built for the purpose at the plant of the Standard Aero Corporation at Elizabeth, New Jersey. The Standard Aero Corporation was engaged, under contract, to set up 10 per cent of the Handley-Page machines complete in this country. These were to be used at our training fields. The engineering details proved to be a serious cause of delay. We found it difficult to install the Liberty engines in this foreign plane. When the armistice cut short operations, 100 complete sets of parts had been shipped to England, and seven complete machines had been assembled in this country. None of the American-built Handley-Page machines saw service in France. There had been great delay in the construction of the assembling plant in England, and the work of setting up the machines had only started when the armistice was signed.

The performance table of the Handley-Page indicates its capacities:

Speed at ground level, 97 miles an hour
Climb to 7,000 feet, 18 minutes, 10 seconds
Climb to 10,000 feet, 29 minutes
Ceiling (14,000 feet), 60 minutes

On its tests 390 gallons of gasoline, 20 gallons of oil, and 7 men were carried, but no guns, ammunition, or bombs.

After a long delay, about January 1, 1918, tentative arrangements had been made with the Caproni interests for the production of Caproni biplanes in this country. These machines had a higher ceiling and a greater speed than the Handley-Page. Captain d'Annunzio, with fourteen expert Italian workmen, came to this country, bringing with them designs and samples, and initiated the redesigning of the Caproni machine to accommodate three Liberty engines. The actual production of Caproni planes in this country was limited to a few samples, which were being tested when the armistice was signed. The factories had tooled up for the production, how-

ever, and in a few months Capronis would doubtless have been produced in liberal quantities.

Test Performances of Caproni Biplane

	Test 1	Test 2
Speed at ground level	100 miles an hour	103.2 miles an hour
Climb to 6,500 feet	16 minutes, 18 seconds	14 minutes, 12 seconds
Climb to 10,000 feet	33 minutes, 18 seconds	28 minutes, 42 seconds
Climb to 11,200 feet	49 minutes	....
Climb to 13,000 feet	....	46 minutes, 30 seconds

As we had produced superlatively good fighting planes built around the Liberty motor, so American invention, with the experience of several months of actual production behind it, was able to bring out, too, an American night-bombing plane that promised to supersede all other types in existence. This machine was designed by Glenn L. Martin in the fall of 1918. It was a night-bomber equipped with two Liberty 12-cylinder engines. The Martin spread of 75 feet gave it a carrying capacity comparable with that of the Handley-Page. Its speed of 118 miles an hour at ground level far exceeded that of either the Caproni or the Handley-Page, and it was evident that its ceiling would be higher than that of the Caproni. (The estimated ceiling of the Martin was 18,000 feet.) The machine never reached the stage of actual quantity production, but several experimental models were built and tested. Being built around its engine, it embodied clean-cut principles of design, and its performances in the air were extraordinary for a machine of its type.

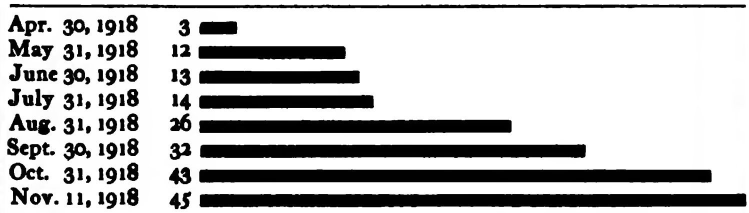
Test Performances of Martin Bomber

	Test 1	Test 2
Speed at ground level	113.3 miles an hour	118.8 miles an hour
Climb to 6,500 feet	10 minutes, 45 seconds	7 minutes
Climb to 10,000 feet	21 minutes, 20 seconds	14 minutes
Climb to 15,000 feet	....	30 minutes, 30 seconds
Total weight	9,663 pounds	8,137 pounds

The total delivery of airplanes to the United States during the period of the war was 16,952. These came from the following sources: United States contractors, 11,754; France, 4,881; England, 258; Italy, 59.

FIGURE 17

*U. S. Airplane Squadrons at the Front**



* A squadron is equipped with from fifteen to twenty-five planes.

Estimates of aircraft strength on the front were always dubious, because of variations in the number of planes in a squadron. The standing of the United States in airplanes at the front is indicated by the estimate of the American Air Service as of November 11, 1918. The figures of this estimate are as follows:

France	3,000
Great Britain	2,100
United States	860
Italy	600
Total	6,560

These figures represent fighting planes equipped ready for service, but do not include replacement machines at the front or in depots, or training machines in France.

The actual strength of the Central Powers in the air is at this time not definitely known to us. Such figures as we have are viewed with suspicion, because of the two methods of observation in reporting an enemy squadron. There may be

Photo from Air Service

THE MARTIN BOMBER

Photo from Air Service

FITTING OUT LEPERE BIPLANES

Photo from Air Service

ARMY AIRPLANES OVER SAN DIEGO

Canadian Official Photograph from Underwood & Underwood, N. Y.

GERMAN ARMORED PLANE SHOT DOWN IN FRANCE

twenty-four planes to a squadron; that is, there may be that number of planes in active service in the air. But each squadron has a complement of replacement planes equaling the number of active planes, so that the squadron might be listed as having forty-eight planes. But we find an approximation of the air strength of the Central Powers in a report from the Chief of the Air Service of the American Expeditionary Forces. This report shows that, on July 30, 1918, Germany had 2,592 planes on the front, and Austria 717.

CHAPTER XVIII

THE LIBERTY ENGINE

THE Liberty engine was America's distinctive contribution to the war in the air, and her chief one. The engine was developed in those first chaotic weeks of preparation of 1917, when our knowledge of planes, instruments, and armament, as then known in Europe, was still a thing of the future. The manufacture of engines for any aëronautical purpose was a task which we could approach with confidence. We possessed in the United States motor engineering talent at least as great as any in Europe; and in facilities for manufacture—in the plants which had built our millions of automobile engines—no other part of the world could compare with us. Therefore, while awaiting word from Europe as to the best types of wings, fuselages, instruments, and the like, we went ahead to produce for ourselves a new, typically American engine which would uphold the prestige of America in actual battle.

Many Americans have doubtless wondered why we built our own engine instead of adopting one or more of the highly developed European engines then at hand; and no doubt our course in this vital matter has sometimes been set down to mere pride in our ability and to an unwillingness to follow the lead of other nations in a science in which we ourselves were preeminent—the science of building light internal-combustion engines. But national pride, aside from giving us confidence that our efforts in this direction would be successful, had little weight in the decision. There were other reasons, and paramount ones—reasons leading directly from the necessity for the United States to arrive at her maximum aërial effort in a minimum of time—that irresistibly compelled the aircraft

production organization to design a standard American engine. Let us examine some of these considerations.

If there was any one truth to be observed from this side of the Atlantic with respect to the tendencies of aircraft evolution in Europe, it was that the horsepowers of the engines were continually increasing, these expansions coming almost from month to month as newer and newer types and sizes of engines were brought out by the European inventors. It was evident to us that there was not a single foreign engine then in use on the western front that was likely to survive the test of time. Each might be expected to have its brief day of supremacy, only to be superseded by something more modern and more powerful. Yet time was an element to which we in this country must give grave consideration. To produce in quantities such as we were capable of producing would ordinarily require a year of maximum industrial effort to equip our manufacturing plants with the machines, tools, and skilled workmen necessary for the production of parts. The finished articles would, under normal circumstances, begin coming in quantity during the second year of our program. It would have been fatal to tool up our plants for the manufacture of equipment that would be out of date by the time we could begin producing it, a year later. The obvious course for the United States to adopt, not only with engines, but with all sorts of aëronautical equipment, was to come into the manufacturing competition, not abreast with European progress, but several strides ahead of it, so that when we appeared on the field it would be with equipment a little in advance, in type and efficiency, of anything the rest of the world had to offer.

This factor of time was a strong element in the decision to produce a standard American engine; for, with the possible exception of the Rolls-Royce, there was no engine in Europe of sufficient horsepower and proved reliability to guarantee that it would retain its serviceableness for the two years upon which we must reckon. There was no other course that we could safely adopt.

And there were other conditions that influenced our con-

clusion. We believed that we could design and produce an engine much more quickly and with much better results than we could copy and produce any accredited foreign model. This proved to be true in actual experience. Along with the production of Liberty engines we went into the quantity manufacture of a number of European engines in this country; and the experience of our engineers and factory executives in this work was anything but pleasant. Among others, we produced in American factories the Gnome, Hispano-Suiza, Le Rhone, and Bugatti engines.

Now, European manufacture of mechanical appliances differs from ours largely in the degree to which the human equation is allowed to enter the shop. In continental practice many of the metallurgical specifications and also of the details of mechanical measurements, limits of requisite accuracy, variations which can be allowed, etc., are not put on paper in detail for the guidance of operators, but are confided to the recollections of the individual workmen. A machine comes in its parts to the assembly room of a foreign factory, and after that it is subject to adjustments on the part of the skilled workmen before its operation is successful. It must, so to speak, be tinkered with before it will go. Nothing of the sort is known in an American factory. When standard parts come together for assembly the calibrations must have been so exact that the machine will function perfectly when it is brought together; and assembling becomes mere routine. Thus, when we came to adopt foreign plans and attempt to adapt them to our practices, we encountered trouble and delay. Thirteen months were required to adapt the Hispano-Suiza 150-horsepower engine to our factory methods and to get the first engine from production tools; eight months were similarly spent in producing the Le Rhone 80-horsepower engines. Both these engines had been in production in European factories for a long time, and we had the advantage of all the assistance which the foreign manufacturers could give us.

These experiences merely confirmed the opinions of American manufacturers that the preparations for the production of

any aviation engine of foreign design—if any such suitable and adequate engine could be found—would require at least as much time as to design and tool up for the production of an American engine. When to this consideration was added the necessity of waiting for several weeks or months for a decision on the part of our aviation authorities, either in the United States or in Europe, as to which of the many types of engines then in use by the Allies should be put into production here, procuring and shipping to this country suitable samples, drawings, and specifications, negotiating with foreign owners for rights to manufacture, etc., there was but one tenable decision to be made, and that was to design and build an all-American engine.

Another factor in the decision was our distance from France, which made it necessary for us to simplify as much as possible the problem of furnishing repair parts. At the time we entered the war the British air service was using or developing thirty-seven different makes of engines. France had forty-six. Should we be lured into any such situation, it might have disastrous results, if only because of the difficulties of ocean transportation. Germany was practically concentrating upon not more than eight engines. Our obvious course was to produce as few types of engines as possible, so as to simplify the problem of manufacturing repair parts and shipping them to the front.

With these considerations in mind, the Equipment Division of the Signal Corps determined, in May of 1917, to go ahead with the design and production of a standard engine for the fighting forces of the aviation branch of the Army.

In the engineering field two men stood out who combined experience in designing internal-combustion engines, which most nearly approached combat engines, with experience in large quantity production. J. G. Vincent, with the engineering staff of the Packard Motor Car Company, had for two years been engaged in research work, and had developed several types of 12-cylinder aviation engines of 125 to 225 horsepower. These were not suitable for military purposes, because of their weight per horsepower; but the work had resulted in the acquirement

of a large collection of data and information which would be invaluable in the design of such an engine as the one proposed, and also in the upbuilding of an efficient experimental organization. Mr. Vincent had also had wide experience in designing internal-combustion motors for quantity production. E. J. Hall, of the Hall-Scott Motor Car Company, had for eight years been developing and, latterly, producing several types of aëronautical engines, which he had delivered into the service of several foreign governments, including Russia, Norway, China, Japan, Australia, Canada, and England. He had also completed and tested a 12-cylinder engine of 300 horsepower, which was of too great weight per horsepower to be suitable for military purposes without modifications. He had thus acquired a broad experience and an invaluable fund of information covering the proper areas and materials for engine parts, and proper methods of tests to be applied to such engines; and in addition he, like Mr. Vincent, had had general experience in quantity production. All this information and experience was of invaluable assistance, not only in designing the new engine, but in determining its essential metallurgical and manufacturing specifications.

These two men were qualified, then, in talent and in practice, to lay down on paper the lines and dimensions of the proposed engine, an engine that would meet the Army's requirements and still be readily capable of prompt quantity production. They had in their hands the power to draw freely upon the past experience and achievement of practically the entire world for any feature which they might decide to install in the model power plant to be produced. And this power applied to the patented features, not only of American motors, but also of foreign engines; for each man had exhaustively studied the leading European engines, including the Mercedes, upon which Germany largely pinned her faith up to the end of the war.

With respect to American motor patents, an interesting situation had arisen in the automobile industry. The leading producers of motor cars were in an association which had adopted an arrangement known as the cross-licensing agree-

ment. Under this agreement all patents taken out by the various producers (with a few exceptions) were thrown into a pool upon which any producer was permitted to draw at will without payment of royalties. A similar arrangement was adopted with respect to the Liberty engine, except that the Government pledged itself to pay an agreed royalty for the use of patents. Thus the engineers, in designing the engine, might reach out and take what they pleased, regardless of patent rights. The result was likely to be a composite type embracing the best features of the best engines ever built. Theoretically, at least, a super-engine ought to result from such an effort.

The ideal aviation engine must produce a maximum of power with a minimum of weight; it must run at its maximum power during a large proportion of its operating time, as an automobile motor seldom, if ever, does for more than a few minutes at a time; and it should consume oil and fuel economically, to conserve space and weight on the airplane. Such was the problem—the design of an engine to meet these requirements—that confronted these two engineers when they were called to Washington and asked to undertake the work.

The many versions of the story of how the experimental models of the Liberty engine were designed and produced justify the use of space here for the exact history of those memorable weeks.

The engine was put on paper in the rooms occupied by Colonel E. A. Deeds at the Willard Hotel in Washington. Colonel Deeds had been the man of broad vision who, by taking into consideration the elements of the problems enumerated above, determined that America could best make her contribution to the aviation program by producing an engine typically her own. He had proposed the plan to his associate, Colonel S. D. Waldon, who had thereupon studied the matter and agreed entirely with the plan. The two officers persuaded Messrs. Hall and Vincent to forego further efforts on their individual developments and to devote their combined skill and experience to the creation of an all-American engine. The

project was further taken up with the European authorities in Washington, and it was supported unanimously.

In these conferences it was decided to design two models of combat engines. Each should have a cylinder diameter of five inches and a piston stroke seven inches long; but one type should have eight cylinders and the other twelve. The 8-cylinder engine should develop 225 horsepower; for all the experts believed then, in May, 1917, that such a motor would anticipate the power requirements of the spring of 1918. The 12-cylinder engine should develop 330 horsepower; for it was believed that this would be the equal of any other engine developed through 1919 and 1920. Every foreign representative in Washington with aëronautical experience agreed that the 8-cylinder 225-horsepower engine would be the peer of anything in use in the spring of 1918; yet, so rapidly was aviation history moving that inside of ninety days it became equally clear that it was the 12-cylinder engine of 330 horsepower, and not the 8-cylinder engine, upon which we should concentrate for the spring of 1918.

With these considerations in mind, Messrs. Hall and Vincent set to work to lay out the designs on paper. With them were Colonel Deeds and Colonel Waldon. It was the function of the officers to insist that nothing untried or experimental be incorporated in the engines; it was the function of the engineers to direct their technical knowledge by this *sine qua non.* The size of the cylinders, five by seven inches, was adopted not only because the Curtiss and the Hall-Scott companies, the largest producers of aviation engines in the United States, had had experience with engines of this size, but also because a new and promising French engine, the Lorraine-Dietrich, which had just made its appearance in experimental form, was an engine of approximately that size.

On May 29, 1917, Messrs. Vincent and Hall set to work. Within two or three days they had outlined the important characteristics of the engine sufficiently to secure—on June 4—the approval of the Aircraft Production Board and of the Joint Army and Navy Technical Board of the building of

Photo from Packard Motor Car Company

FORGINGS FOR LIBERTY ENGINE CYLINDERS

Photo from Packard Motor Car Company

GIRL STUDENT MECHANICS AT TRAINING SCHOOL OF LIBERTY ENGINE FACTORY

Photo from Packard Motor Car Company

LIBERTY ENGINES MOVING DOWN ASSEMBLING LINE

Photo from Packard Motor Car Company

ADJUSTING IGNITION SYSTEM OF LIBERTY ENGINES

five experimental models each of the 8-cylinder and the 12-cylinder sizes.

The detail and manufacturing drawings of the two engines were made partly by the staff of the Packard Motor Car Company, under Mr. O. E. Hunt, and partly by an organization recruited from various automobile factories and put to work under Mr. Vincent at the Bureau of Standards at Washington. Due credit must here be given to Dr. S. W. Stratton, the director of that important governmental scientific bureau. The Liberty engine pioneers woke him up at midnight and told him of their needs. He promptly tendered all the facilities of the Bureau of Standards, turning over to the work an entire building for use the following morning. Thereafter Dr. Stratton gave to the work the closest coöperation of himself and his assistants.

While the detail drawings were being made, the parts for the ten engines were at once started through the tool rooms and experimental shops of various motor car companies. This work centered in the plant of the Packard Company, which gave to it its entire energy and its splendid facilities.

Every feature in the design of these engines was based on thoroughly tested practice of the past. That the engine was a composite is shown by the origins of its various parts:

Cylinders: The Liberty engine derived its type of cylinder from the German Mercedes, the English Rolls-Royce, the French Lorraine-Dietrich, and others produced both before and during the war. The cylinders were steel inner shells surrounded by pressed-steel water jackets. The Packard Company had developed a practical production method of welding together the several parts of a steel cylinder.

Cam shafts and valve mechanism above cylinder heads: The design of these was based on the general arrangement of the Mercedes and Rolls-Royce, and improved by the Packard Motor Car Company for automatic lubrication without waste of oil.

Cam-shaft drive: The general type was that used on the

Hall-Scott, Mercedes, Hispano-Suiza, Rolls-Royce, Renault, Fiat, and others.

Angle between cylinders: In the Liberty the included angle between cylinders was 45 degrees. This angle was adopted to save head resistance, to give greater strength to the crank case, and to reduce periodic vibration. This decision was based on experience with the Renault and Packard engines.

Electric generator and ignition: The Delco system was adopted, but specially designed for the Liberty, to provide a reliable double ignition.

Pistons: The die-cast aluminum-alloy pistons of the Liberty were based on development work by the Hall-Scott Company under service conditions.

Connecting rods: These were of the forked or straddle type used on the DeDion and Cadillac automobile motors, and also on the Hispano-Suiza and other aviation engines.

Crank shaft: A design of standard practice, every crank pin operating between two main bearings, as in the Mercedes, Rolls-Royce, Hall-Scott, Curtiss, and Renault.

Crank case: A box section carrying the shaft in bearings clamped between the top and bottom halves by means of long through bolts, as in the Mercedes and Hispano-Suiza.

Lubrication: The system of lubrication was changed, this being the only change of design made in the Liberty after it was first put down on paper. The original system combined the features of a dry crank case, as in the Rolls-Royce, with pressure feed to the main crank-shaft bearings and scupper feed to the crank-pin bearings, as in the Hall-Scott and certain foreign engines. The system subsequently adopted added pressure feed to the crank-pin bearings, as in the Rolls-Royce, Hispano-Suiza, and other engines.

Propeller hub: Designed after the practice followed by such well-known engines as the Hispano-Suiza and Mercedes.

Water pump: The conventional centrifugal type was adapted to the Liberty.

Carburetor: The Zenith type was adapted to the engine.

As the detail and manufacturing drawings were completed

in Washington and Detroit they were taken to various factories where the parts for the first engine were built.

The General Aluminum & Brass Manufacturing Company of Detroit made the bronze-back, babbitt-lined bearings.

The Cadillac Motor Car Company of Detroit made the connecting rods, the connecting-rod upper-end bushings, the connecting-rod bolts, and the rocker-arm assemblies.

The L. O. Gordon Manufacturing Company of Muskegon, Michigan, made the cam shafts.

The Park Drop Forge Company of Cleveland made the crank-shaft forgings. These forgings, completely heat treated, were turned out in three days, because Mr. Hall gave the Cleveland concern permission to use the Hall-Scott dies.

The Packard Motor Car Company machined the crank shafts and all parts not furnished or finished elsewhere.

The Hall-Scott Motor Car Company of Berkeley, California, made all the bevel gears.

The Hess-Bright Manufacturing Company of Philadelphia made the ball bearings.

The Burd High-Compression Ring Company of Rockford, Illinois, made the piston rings.

The Aluminum Castings Company of Cleveland made the die-cast alloy pistons and machined them up to grinding.

The Rich Tool Company of Chicago made the valves.

The Gibson Company of Muskegon, Michigan, made the springs.

The Packard Company made all the patterns for the aluminum castings, which were produced by the General Aluminum & Brass Manufacturing Company of Detroit.

The Packard Motor Car Company used many of its own dies in order to obtain suitable drop forgings speedily, and also made all necessary new dies not made elsewhere.

As these various parts were turned out they were hurried to the tool room of the Packard Company, where the assembling of the model engines was in progress.

Before the models were built, however, extraordinary precautions had been taken to ensure that the mechanism should

be as perfect as American engineering skill could make it. The plans as developed were submitted to H. M. Crane, the engineer of the Simplex Motor Car Company and of the Wright-Martin Aircraft Corporation, who had made a special study of aviation engines in Europe, and who for upward of a year had been working on the production of the Hispano-Suiza 150-horsepower engine in this country. He looked the plans over, and so did David Fergusson, chief engineer of the Pierce-Arrow Motor Car Company. Many other of the best experts in the country in the production of internal-combustion motors constructively criticized the plans, these including such men as Henry M. Leland and George H. Layng, of the Cadillac Motor Car Company, and F. F. Beall and Edward Roberts, of the Packard Motor Car Company.

When the engineers were through, the practical production men were given their turn. The plane and engine builders examined the plans to make sure that each minute part was so designed as to make it most adaptable to quantity production. The scrutiny of the Liberty plans went back in the production scale even farther than this; for the actual builders of machine tools were called in to examine the specifications and to suggest modifications, if necessary, that would make the production of parts most feasible in machine tools either of existing types or of easiest manufacture.

Thus scrutinized and criticized, the plans of the engine were from every point of view the best that American industrial genius could produce in the time available. It was due to this exhaustive preliminary study that no radical changes were ever made in the original design. The Liberty engine was not the materialization of magic nor the product of any single individual or company: it was a well-considered and carefully prepared design based on large practical aviation-engine experience.

On July 4, 1917, the first 8-cylinder Liberty engine was delivered in Washington. This was less than six weeks after Messrs. Hall and Vincent drew the first line of their plans. The same procedure was even then being repeated for the 12-

cylinder engine. By the 25th day of August the model 12-cylinder Liberty had successfully passed its fifty-hour test. In this test its power ranged from 301 to 320 horsepower. As an achievement in speed in the development of a successful new engine, this performance had never been equaled in the motor history of any country. No successful American automobile motor was ever put into production under a year of trial and experimentation. We may well believe that in the third year of war the European aviation designers were working at top speed to improve the motive power of airplanes; yet in 1917 the British war cabinet report contained the following language:

> Experience shows that as a rule, from the date of the conception and design of an aëro engine, to the delivery of the first engine in series by the manufacturer, more than a year elapses.

But America designed and produced experimentally a good engine in six weeks and a great one in three months, and began delivering it in series in five months. This record was due to the fact that we could employ our best engineering talent without stint, to the further fact that there were no restrictions upon our use of designs and patents proved successful by actual experience, and to the fact that the original engine design produced under such conditions stood every expert criticism and test that could be put upon it and emerged from the trial without substantial modification.

As soon as the first Liberty models had passed their official tests, plans were at once made to put them into manufacture. The members of the Aircraft Production Board chose for the chief of the engine production department Harold H. Emmons, an attorney and manufacturer of Detroit, Michigan, who, as a lieutenant in the Naval Reserve Force, was just being called by the Navy Department into active service. The production of all aviation engines, for both Army and Navy, was in his hands throughout the rest of the war. He placed orders for 100,993 aviation engines of all types, which involved the expenditure of $450,000,000 and more of government funds. Of these, 31,814 were delivered ready for service

before the signing of the armistice. The United States reached a daily engine production greater than that of England and France combined.

In August, 1917, it was intended to manufacture both engines, the 8-cylinder and the 12-cylinder, and an agreement was reached with the Ford Motor Company of Detroit to produce 8-cylinder Liberty engines to the number of 10,000. But before this contract could be signed the increasing powers of the newest European air engines indicated to our commission abroad that we should concentrate our manufacturing efforts upon the 12 alone, that being an engine of a power then distinctly in advance of the rapid evolution of aviation engines. The engine production department, therefore, entered into contracts for the construction of 22,500 of the 12-cylinder Liberties, and the first of these contracts was signed in August, a few days after the endurance tests had demonstrated that the 12-cylinder engine was a success.

Of this number of Liberty engines, the Packard Motor Car Company contracted to build 6,000; the Lincoln Motor Company, 6,000; the Ford Motor Company, 5,000; Nordyke & Marmon, 3,000; the General Motors Corporation (Buick and Cadillac plants), 2,000; and an additional contract of 500 engines was let to the Trego Motors Corporation.

Early in the Liberty engine project it became evident that one of the great stumblingblocks to volume production would be the steel cylinder, if it were necessary to machine it out of a solid or partially pierced forging such as is used for shell making. This problem was laid before Henry Ford and the engineering organization of the Ford Motor Company at Detroit, and they developed the unique method of making the cylinders out of steel tubing. One end of the tube was cut obliquely, heated, and in successive operations closed over and then expanded into the shape of the combustion chamber, with all bosses in place on the dome. The lower end was then heated and upset in a bulldozer until the holding-down flange had been extruded from the barrel at the right place. By this method a production of 2,000 rough cylinders a day was

reached. The final forging was so near to the shape desired that millions of pounds of scrap were saved over other methods, to say nothing of an enormous amount of labor done away with. The development of this cylinder-making method was one of the important contributions to the quantity production of Liberty engines.

It was evident that in the actual production of the Liberty engine there would continually arise practical questions of manufacturing policy that might entail modifications of the manufacturing methods; and our aviation authorities in Europe could be expected to advance suggestions from time to time that might need to be embodied in the mechanism. Consequently it was necessary to create a permanent development and standardization administration for the Liberty engine. Nor could this supervision be located in Washington, because of the extreme need for haste: it must exist in the vicinity of the plants which were doing the manufacturing. For this reason the production of the Liberty engine was centered in the Detroit manufacturing district. In this district was located the principal motor-manufacturing-plant capacity of the United States. James G. Heaslet, formerly general manager of the Studebaker Corporation and an engineer and manufacturer of wide experience, was installed as district manager. The problems incident to the inspection and production of the Liberty engine were placed in charge of a committee consisting of Major Heaslet (chairman); Lieutenant Colonel Hall, one of the designers of the engine; Henry M. Leland; C. Harold Wills, of the Ford Motor Company; and Messrs. F. F. Beall and Edward Roberts, of the Packard Motor Car Company. With them were also associated D. McCall White, the engineer of the Cadillac Motor Company, and Walter Chrysler, of the Buick Company.

The creation of this committee virtually made a single manufacturing concern of the several, previously rival, motor companies engaged in producing the Liberty engine. To these meetings the experts brought without reservation the trade secrets and shop processes developed in their own establish-

ments during the preceding years of competition. Such coöperation was without parallel in the history of American industry, and only a great emergency such as the war with Germany could have brought it about. It aided wonderfully in the development and production of the Liberty engine.

Moreover, the Government drew heavily upon the talent of these great manufacturing organizations for meeting the special problems presented by the necessity of filling in the briefest possible time the largest aviation engine order ever known. Short cuts that these firms might have applied effectively to their own private advantage were devised for the Liberty engine and freely turned over to the Government. The Packard Company gave a great share of its equipment and *personnel* to the development. The most conspicuous success in the science of quantity production in the world was the Ford Motor Company, which devoted its organization to the task of speeding up the output of Liberty engines. In addition to the unique and wonderfully efficient method of making rough engine cylinders out of steel tubing, the Ford organization also perfected for the Liberty a new method of producing more durable and satisfactory bearings. Messrs. H. M. and W. C. Leland, whose names are indissolubly linked with the Cadillac automobile, organized and erected the enormous plant of the Lincoln Motor Company and equipped it for the production of the Liberty, at a total expense of approximately $8,000,000.

Balanced against these advantages brought by highly trained technical skill and unselfish coöperation were handicaps such as perhaps no other great American industrial venture had ever known. In the first place, an internal-combustion engine with cylinders of 5-inch bore and pistons of 7-inch stroke—the Liberty measurements—was larger than the automobile engines then in use in this country. This meant that, while we apparently had an enormous plant—the combined American automobile factories—ready for the production of Liberty engines, actually the machinery in these plants was not large enough for the new work, so that new machinery must be built. In some instances machinery had to be designed

anew for the special purpose. To produce every part of one Liberty engine, something between 2,500 and 3,000 small jigs, tools, and fixtures are employed. For large outputs, much of this equipment must be duplicated over and over again. To provide the whole joint workshop with this equipment was one of the unseen jobs incidental to the construction of Liberty engines—unseen, that is, by the general public. Yet it compelled the United States to commandeer the capacity of all available tool shops east of the Mississippi River and devote it to the production of jigs and tools for the Liberty engine factories.

Then there was the question of mechanical skill in the factories. It was soon clear that an automobile motor is a simple mechanism compared with an aviation engine. The machinists in ordinary automobile plants did not have the skill to produce the Liberty engine parts successfully. Consequently it became necessary to educate thousands of mechanics, men and women alike, to do this new work.

It was surprising to what extent unfriendly influence in the United States, much of it probably of pro-German inclination, cut a figure in the situation. This was particularly true in the supply factories which furnished tools to the Liberty engine plants. Approximately 85 per cent of the tools first delivered for this work were found to be inaccurate and incorrect. These had to be remade before they could be used. Such tools as were delivered to the Liberty plants would mysteriously disappear, or vital equipment would be injured in unusual ways; in several instances cans of explosives were found in the coal at power plants; fire-extinguishing apparatus was discovered to have been rendered useless by acts of depredation; and from numerous other evidences the builders of Liberty engines were aware that the enemy had his agents in their plants.

Difficulty was also experienced in the production of metals for the new engines. The materials demanded were frequently of a much higher grade than the corresponding materials used in ordinary automobile motors. Here was another unseen phase

of development which had to be worked out patiently by the producers of raw materials.

Difficulties in transportation during the winter of 1917-1918 added their share to the perplexing problems of the engine builders; and at times the scarcity of coal threatened the complete shutdown of some of the plants.

Against such obstacles, the engine-production department forced the manufacture of the Liberty engine at a speed never before known in the automotive industry. In December, 1917, the Government received the first twenty-two Liberty engines of the 12-cylinder type, durable and dependable, a standardized, concrete product, only seven months after the Liberty engine existed merely as an idea in the brains of two engineers. These first engines developed approximately 330 horsepower; and so also did the first 300 Liberty engines delivered, these deliveries being completed in the early spring of 1918.

When the Liberty engine was designed, our aviation experts believed that 330 horsepower was so far in advance of the development of aëro engines in Europe that we could safely go ahead with the production of this type on a quantity basis. But again we reckoned without an accurately prophetic knowledge of the course of engine development abroad. We were building the first 300 Liberty engines at 330 horsepower when our aviation reports informed us from overseas that an even higher horsepower would be desirable. Therefore our engineers "stepped up" the power of the Liberty 12-cylinder engine to 375 horsepower. Several hundred motors of this power were in process of completion when, once more, our observers in France advised us that, by adding another twenty-five horsepower to the Liberty and making it 400 horsepower in strength, we could be sure of leading all the combatant nations in size and power of aviation engines during 1918 and 1919. This last step, we were assured, was the final, definitive one. But to anticipate possible extraordinary development of engines by other nations, our engineers went even farther than the mark advised by our overseas observers and raised the horsepower of the Liberty engine to something in excess of 400.

This enormous increase over the original power of the Liberty engine required changes in the construction; notably, increases in the strength of practically all the working parts, including the crank shaft, the connecting rods, and the bearings. The change also resulted in making scrap iron of a large quantity of the jigs and special tools employed in making the lighter engines. A still further change had to come in the grade of the steel used in some of the parts, and this went back to the smelting plants, where new and better methods of producing steel and aluminum for the Liberty engine had to be developed. Thus, although there were no fundamental changes in the design of the engine, the increase of its power required a considerable readjustment in the engine plants. So rapidly were these changes made that on the first anniversary of the day when the design of the Liberty engine was begun—May 29, 1918—the Signal Corps had received 1,243 Liberty engines. In this achievement, motor history was written in this country as never before.

From a popular standpoint it may seem as if the Liberty engine were radically changed after its inception, but it was not. In the fundamental thing, the design, there was but one change made after the engine was laid down on paper in May, 1917: namely, that in the oiling system. The original Liberty engine was partially fed with oil by the so-called scupper system, whereas this was later changed to a forced feed under compression. The scupper feed worked successfully, but the forced feed is foolproof and was therefore installed upon the advice of the preponderance of expert criticism. It is also true that in working out certain practical manufacturing processes some of the original measurements were altered. But this is a common experience in the manufacture of any internal-combustion engine, and alterations made for factory expediency are not regarded as changes in design, nor are they important.

The delivery of twenty-two motors in December of 1917 was followed by the completion of forty in January, 1918. In February the delivery was seventy. In March this jumped to

122; then came a leap in April to 415; and in May the deliveries amounted to 620.

The quantity production of Liberties may be said to have started in June, 1918, one year after the conception of the engine in Washington. In that month 1,102 motors of the most powerful type were delivered to the service. In July the figure was 1,589; in August, 2,297; in September, 2,362. Then in October came an enormous increase to the total of 3,878 Liberty engines. During the month before the armistice was signed, the engine factories were producing 150 engines a day.

In all, up to November 29, 1918, 15,572 Liberty engines were produced in the United States. In the disposal of them the American Navy received 3,742 for its seaplanes; the plants manufacturing airplanes in this country took 5,323 of them;

FIGURE 18

Liberty Engines Produced Each Month during 1918

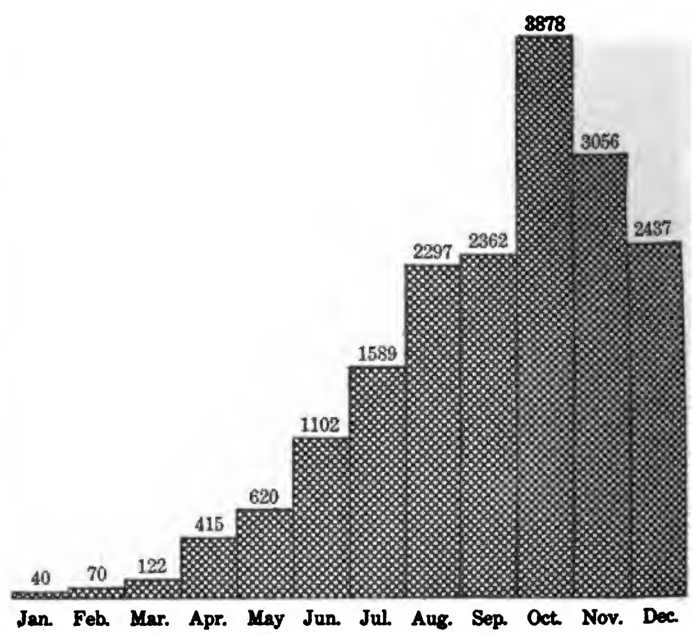


Photo from Packard Motor Car Company

TESTING FIELD FOR LIBERTY ENGINES

Photo from Packard Motor Car Company

LIBERTY ENGINES READY FOR SHIPMENT